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THE DEVELOPMENT OF STATIC AND DYNAMIC MODELS OF THE EARTH'S RADIATION
BELT ENVIRONMENT THROUGH THE STUDY OF PLASMA WAVES, WAVE-PARTICLE
INTERACTIONS AND PLASMA NUMBER DENSITIES FROM IN SITU OBSERVATIONS IN
THE EARTH'S MAGNETOSPHERE WITH THE CRRES SPACERAD INSTRUMENTS

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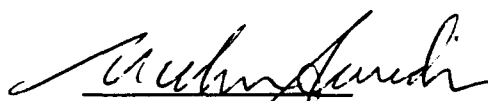
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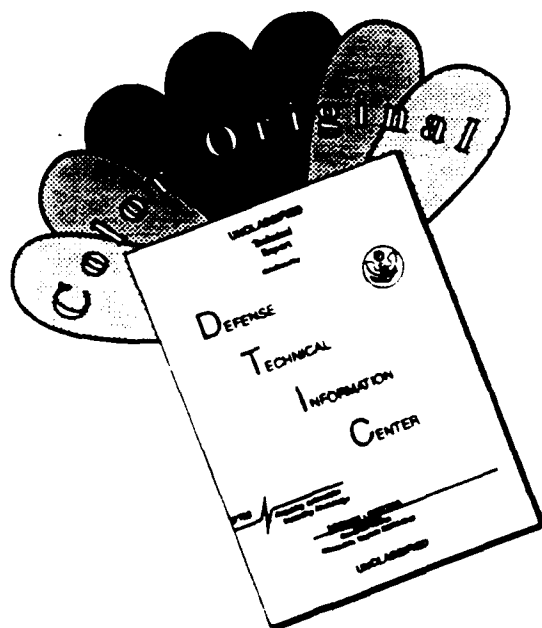
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13. ABSTRACT (Maximum 200 words) This report describes the achievements of the first year of effort on data acquired by The University of Iowa/AFGL Plasma Wave Experiment (PWE) (AFGL 701-15 Passive Plasma Sounder and AFGL 701-13-2 Search Coil Magnetometer) which was a part of the SPACERAD complement of instruments on the Combined Release and Radiation Effects Satellite (CRRES). The primary purpose of the PWE is to study plasma waves, wave-particle interactions, and plasma number densities in the radiation belts of the Earth's magnetosphere as observed by the CRRES SPACERAD instruments in order to provide essential parameters for understanding both the long-scale and short-scale temporal and spatial variations of the individual particle species and waves and their inter-relationships. Computer programs to display and analyze the CRRES PWE data from both the real-time data collected at CSTC (The U.S. Air Force's Consolidated Space Test Center at Onizuka AFB in Sunnyvale, California) and the Agency Tapes have been developed and utilized to study the PWE data and to extract the electron number density throughout the CRRES orbit. Many significant new discoveries have been made including detailed observations of the fine structure in density variations and their association with enhanced low frequency electric field emissions, observations of deep cavities and ducts within the plasmasphere, and detection of multiple bands of emissions associated with multiple populations of energetic electrons.				
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1. INTRODUCTION

This document constitutes the first annual technical report on the Air Force Contract F19628-90-K-0031 with The University of Iowa for the Development of Static and Dynamic Models of the Radiation Belt Environment through the Study of Plasma Waves, Wave-Particle Interactions, and Plasma Number Densities in the Radiation Belts of the Earth's Magnetosphere. The primary purpose of the investigation is to study plasma waves, wave-particle interactions, and plasma number densities in the radiation belts of the Earth's magnetosphere as observed by the Combined Release and Radiation Effects Satellite (CRRES) SPACERAD instruments in order to provide essential parameters for understanding both the long-scale temporal and spatial variations of the individual particle species and waves and their inter-relationships. The primary CRRES instrument involved in this investigation is The University of Iowa/Phillips Laboratory (formerly Geophysics Laboratory (GL) and Air Force Geophysics Laboratory (AFGL)) Plasma Wave Experiment which is comprised of the CRRES SPACERAD AFGL-701-15 (Passive Plasma Sounder) and AFGL-701-13-2 (Search Coil Magnetometer) experiments.

The measurement and study of the plasma wave environment in the radiation belts are essential to the SPACERAD mission because plasma waves play a major role in changing the energetic particle population through pitch angle scattering, ion and electron heating, and other wave-particle interaction processes which exchange energy and/or momentum between the waves and the particles. Evaluation of the plasma wave data allows the characterization of the plasma waves and the measurement of the electron number density. Characterization of the

plasma waves includes determining the spectral characteristics (intensity as a function of frequency), polarization (intensity as a function of angle between the antenna and the ambient magnetic field) and the degree to which the waves are electromagnetic or electrostatic by comparing the measurements from the search coil magnetometer and the long electric antennas. The characterization of the plasma waves is important for identifying the wave modes taking part in the wave-particle interaction processes and for evaluating the effect of the waves on the particles. The plasma wave data from CRRES allows a sheath-independent determination of the total electron number density throughout CRRES orbit. The electron number density is a necessary parameter for evaluating wave dispersion relations and determining the resonant energies in the various wave-particle interaction processes. Using the assumption of charge neutrality, the measurement of the total electron number density can also be used to determine the number density of low energy ions not detectable due to spacecraft sheath effects or detector characteristics. A comparison of the plasma wave measurements with the plasma and energetic particle measurements are used to study the various wave-particle interaction processes both on a statistical basis for long-term modelling studies and on a short-term event basis such as during magnetic storms.

The CRRES Plasma Wave Experiment was designed to adequately measure the plasma wave environment in the Earth's radiation belts with emphasis on high frequency and time resolution, a large dynamic range, and sufficient frequency response to cover the majority of the characteristic frequencies of the plasma that are of interest and to determine the electron number density continuously over the range from

10^{-2} to $2 \times 10^3 \text{ cm}^{-3}$ using passive sounding techniques. The CRRES Plasma Wave Experiment provides measurements of electric fields from 5.6 Hz to 400 kHz and magnetic fields from 5.6 Hz to 10 kHz with a dynamic range of at least 100 dB. Electrostatic dN/N measurements from 5.6 Hz up to 400 kHz are also possible via signals from the Langmuir Probe Experiment. The 5.6 Hz to 400 kHz frequency range of the CRRES Plasma Wave Experiment covers most of the important characteristic frequencies expected to be encountered by CRRES in the region above about $2 R_E$ (Earth radii). Below about $2 R_E$ when the plasma frequency exceeds 400 kHz, the Langmuir Probe Experiment can provide the electron number density measurements. Electromagnetic plasma waves below 5.6 Hz are in the frequency range covered by the Fluxgate Magnetometer Experiment. Electric field fluctuations below 5.6 Hz can be measured by the Langmuir Probe Experiment.

The Plasma Wave Experiment primary sensors consist of an extendable 100-meter tip-to-tip fine wire long electric dipole antenna (designated WADA for Wire Antenna Deployment Assembly) and a search coil magnetometer mounted on an Astromast boom 6 meters away from the spacecraft. The primary sensors for the Langmuir Probe Experiment, double spherical probes separated by about 100 meters (designated SWDA for Spherical-probe Wire Deployment Assembly) can also be used for either electric field measurements (when the Langmuir Probe Experiment is in the Voltage mode) or electrostatic dN/N measurements (when the Langmuir Probe Experiment is in the Current mode) by the Plasma Wave Experiment.

The basic CRRES Plasma Wave Instrumentation includes two receivers: (1) a 128-channel Sweep Frequency Receiver (SFR) for high-

frequency-resolution spectrum measurements from 100 Hz to 400 kHz and (2) a 14-channel Spectrum Analyzer (SA) to provide high-time-resolution spectra from 5.6 Hz to 10 kHz. The dynamic range for both of the receivers is about 100 dB (a factor of 10^5 in amplitude) beginning at the respective receiver's noise level.

The Sweep Frequency Receiver covers the frequency range from 100 Hz to 400 kHz in four bands with 32 logarithmically-spaced steps per band. The fractional step separation of the Sweep Frequency Receiver, df/f , is about 6.7% across the entire frequency range. Band 1 (100 Hz to 810 Hz) is sampled one step per second or 32 seconds per sweep. Band 2 (810 Hz to 6.4 kHz) is sampled two steps per second or 16 seconds per sweep. Band 3 (6.4 kHz to 51.7 kHz) and Band 4 (51.7 kHz to 400 kHz) are each sampled four steps per second or 8 seconds per sweep. The nominal bandwidths of the four bands are 7 Hz, 56 Hz, 448 Hz, and 3.6 kHz, respectively. The four bands each have a logarithmic compressor which measures the signal amplitude over about a 100 dB dynamic range beginning at the noise level of the receiver and produces a 0.0 to 5.10 Volt DC analog output proportional to the logarithm of the input amplitude.

The Multichannel Spectrum Analyzer consists of 14 narrow-band filters logarithmically spaced in frequency (4 filters per decade in frequency) from 5.6 Hz to 10 kHz followed by 14 logarithmic compressors each having a dynamic range of about 110 dB. The nominal 3 dB sine wave bandwidth of each narrow-band filter is $\pm 15\%$ of the center frequency except for the two highest frequency channels (5.62 kHz and 10.0 kHz) whose bandwidths are $\pm 7.5\%$ of the center frequency. The 14

0.0 to 5.10 Volt DC analog outputs are sampled simultaneously 8 times per second to produce high time resolution spectra.

The Spacecraft Telemetry Data System provides the clock and command lines for controlling the receivers and the sampling and the analog to digital conversions of the receivers' 0.0 to 5.10 Volt DC analog outputs. The CRRES Plasma Wave Experiment has two high-level relay commands and one 16-bit serial command. The high-level relay commands turn the experiment power on and off. The serial command determines which sensor is connected to which receiver and whether or not the receivers are locked onto a single sensor or cycle through all of the sensors. When the SFR is commanded to the cycle mode (CYCLE1), its input is cycled E-B-E-LANG at a 32 second per sensor rate (E is the long electric dipole antenna; B is the search coil magnetometer; and LANG is the input from the Langmuir Probe Experiment). When the SA is commanded to the cycle mode (CYCLE2), its input is cycled B-E-B-LANG at a 4 second per sensor rate. The modes of the two receivers are independent of each other. A complete description of the CRRES Plasma Wave Experiment is included in Appendix 1 of this report.

Many spacecraft have flown through the radiation belts over the past 32 years but none have been so ideally suited to study the radiation belt environment as the SPACERAD part of CRRES is. The extensive complement of plasma and particle instruments provide details of the particle distribution functions not generally available before. Between the CRRES Plasma Wave Experiment, the University of California, Berkeley (UCB)/AFGL 701-14 Electric Field/Cold Plasma Langmuir Probe experiment, and the AFGL/UCB 701-13 Fluxgate Magnetometer Experiment substantially more and higher-quality data are available on the

electron number density and temperature and plasma wave environment in the radiation belts than has been available before. Extremely important features of these experiments include the large frequency range (DC to 400 kHz) and the high sensitivity allowed by the long (100 m tip-to-tip) electric field antennas.

Plasma wave data from the ISEE spacecraft (upon whose original design the sweep frequency receiver, 5.6 Hz to 10 kHz spectrum analyzer, and search coil magnetometer were derived) have shown the wealth of plasma wave characteristics and electron number density data available from such instrumentation. For radiation belt studies the CRRES orbit is much more ideal than was ISEE's orbit. CRRES has about a 10 hour near-equatorial (18 degree inclination) orbit while ISEE had a 57 hour orbit inclined at about 30 degrees. Combined with the dipole offset, this resulted in ISEE spending little time in the equatorial radiation belts. In addition, some of the most important particle detectors on ISEE were turned off while going through the radiation belts. GEOS 1 ended up going through the radiation belts by accident because of the failure to achieve the proper orbit. Thus, its instrumentation was not ideally suited for radiation belt studies. For instance, the upper frequency limit on the plasma wave experiment was 77 kHz. SSS-A had an ideal orbit for studying the radiation belt but had a limited frequency range (3 kHz magnetic and 100 kHz electric), very short antennas (about 5 m tip-to-tip) and no sweep frequency receiver. This provided only a very crude and limited range of number density measurements and little detail for the plasma wave observations above the 10 kHz upper limit of the wideband analog receiver. Dynamics Explorer 1 had an excellent complement of plasma wave receivers but

several of the particle detectors became inoperable early in the mission. In addition, because of its polar inclination and the fact that it is on only about one third of the time, Dynamics Explorer 1 has significantly less data from the equatorial radiation belts than what has been obtained from CRRES.

Several outstanding problems in space plasma physics that will aid in our understanding of the radiation belt environment and its dynamical changes are addressed in this investigation. One is "What effects do changes in the amount of cold plasma at different locations in the magnetosphere have on the energetic particle distribution functions?". In terms of measurable or derivable quantities obtainable from the CRRES Plasma Wave Experiment this translates into "What is the electron number density and how does it vary as a function of position, time, geomagnetic conditions, and changes in the plasma and energetic particle distribution functions?". The plasma number density has a strong control on many wave-particle interactions. The resonant energy for many electromagnetic wave-particle interactions is a function of $B^2/8\pi N$ where B is the magnitude of the ambient magnetic field and N is the number density. The generation of electrostatic electron cyclotron harmonic waves which can lead to the rapid loss of energetic electrons is believed to be strongly dependent on the ratio of hot to cold particle number densities. In addition to being important for calculations of resonant energies and dispersion relations, the electron number density is also useful for identifying the region of space being sampled such as the plasmasphere, plasmopause, trough, magnetopause, or magnetosphere. A number of wave-particle interactions are expected to be most intense near the equatorial plasmopause because

of the minima in the ambient magnetic field and the steep gradient in number density.

A second important question is "What is the relationship in the radiation belts between the observed plasma wave characteristics and changes in the plasma and energetic particle distribution functions?". A crucial part in understanding this relationship is identifying the plasma wave modes present and measuring their intensities. Identification of the plasma wave modes requires determination of the spectral characteristics (intensity versus frequency as a function of time), electrostatic versus electromagnetic properties, and polarization.

In addition to the above studies involving the natural radiation belt environment, the CRRES Plasma Wave Experiment has also made important contributions for carrying out and supporting active experiments and for studying the effects of man-made injected chemical releases and electromagnetic radiation from ground transmitters. CRRES is important for these studies because of its orbit and its complement of experiments. Because the CRRES spacecraft is in the middle of the CRRES GTO chemical releases, its experiments are extremely important for the in situ wave, fields, and particle measurements. The CRRES orbit is also especially desirable for the wave-wave and wave-particle interaction studies using ground transmitters. Many of the interactions stimulated by these experiments are concentrated near the equator in the altitude range covered by the CRRES orbit and could be expected to precipitate particles out of the radiation belts.

In the following sections of this report we will describe the CRRES Plasma Wave Experiment status and operations, progress and

current activities related to the questions, investigations, and studies described above, and future plans. In the final section we acknowledge the contracts and personnel related to the CRRES Plasma Wave Experiment.

2. EXPERIMENT STATUS AND OPERATIONS

Contract F19628-90-K-0031 for the Development of Static and Dynamic Models of the Earth's Radiation Belt Environment through the Study of Plasma Waves, Wave-Particle Interactions, and Plasma Number Densities from in situ Observations in the Earth's Magnetosphere with the CRRES SPACERAD Instruments began at The University of Iowa on April 27, 1990. This report covers the approximately one year time period from then until April 30, 1991.

CRRES was launched from Cape Kennedy (Cape Canaveral Air Force Station, Florida) on July 25, 1990, (day 90-206) into an elliptical orbit with an 18 degree inclination, an initial perigee altitude of 350 km, an apogee altitude of 33,700 km (6.29 R_E geocentric), and an orbital period of 9.88 hours. The CRRES Plasma Wave Experiment was turned on at 14:58:09 GMT (Greenwich Mean Time which is also equivalent to UT or Universal Time) on July 28, 1990, (day 90-209) during Orbit 6. Various CRRES Plasma Wave Experiment Serial/Digital Antenna Selection commands were successfully exercised in order to monitor the conducted noise observed before any booms or antennas were extended. Between 14:58 GMT and 15:06 GMT on 90-209 the SFR and SA were first locked onto the WADA sensors, then onto the SWDA sensors, and finally onto the Search Coil Magnetometer. From 15:06 GMT until 22:10 GMT (near apogee on Orbit 7) on 90-209 the SFR and SA were both operated in their cycle modes. From 22:10 GMT on 90-209 until about 3 1/2 days later after the magnetometer boom deployment and until just before the beginning of the electric antenna extensions, the SFR and SA were both locked onto the Search Coil Magnetometer. Even with the search coil magnetometer stowed up against the spacecraft, we were able to detect banded chorus

and other natural electromagnetic emissions quite clearly up to 10 kHz and still detectable up to nearly 20 kHz (the sensitivity of the search coil magnetometer drops off rapidly after 10 kHz). The instrument remained on until the magnetometer boom deployment on July 31, 1990, during Orbit 14. The instrument was commanded off during the magnetometer boom deployment to avoid the possibility of a temporary short occurring when the cables inside the mast were unraveling. The instrument was commanded off at 19:24:25 GMT on July 31, 1990, (day 90-212). The instrument was turned back on approximately 15 minutes later at 19:39:31 GMT when the magnetometer boom extension was thought to be complete. The instrument has remained on continuously since then except once when it was commanded off due to error on the part of the spacecraft controllers and for long shadow periods late in 1990 and early 1991.

Analyses of the Fluxgate Magnetometer Experiment data after the mast extension revealed that the T-bar at the end of the mast did not snap into place and that the desired orientations for the Fluxgate and Search Coil Magnetometer sensors were not fully achieved. Subsequent investigations determined that the most probable cause for the lack of full extension was that cabling to the sensors routed through a hole in the plate at the end of the mast was being restricted from moving through the hole by the thermal blankets on the plate. The failure of the magnetometer mast to fully extend increases the complexity of the data analysis programs as the axis of the search coil magnetometer is no longer perpendicular to the spacecraft spin axis as it was intended to be. A possible adverse effect on the science could occur if the offset angle from the perpendicular precluded the search coil

magnetometer from sampling the entire range of angles with respect to the ambient magnetic field. If the sampling range were limited, some science would be lost. However, since the difference from perpendicular is on the order of only 15 to 18 degrees, the amount of lost or degraded science will be fairly small. The increased complexity of the data analysis programming required as a result of the incomplete magnetometer boom extension does increase the amount of effort required for the CRRES data reduction and analysis programming.

Before the magnetometer boom deployment several interference lines from clock lines and power converters were visible in the SFR data when it was connected to the Search Coil Magnetometer. After the magnetometer boom deployment, the only significant interference line remaining was a strong signal between 13 and 13.5 kHz which is due to the drive frequency signal for the Fluxgate Magnetometer Experiment mounted about 0.5 meter away from the Search Coil Magnetometer.

The first electric field antenna extension occurred on August 1, 1990, (day 90-213) during Orbit 15. The SFR and SA were commanded to lock onto the SWDA sensors at 08:10 GMT on 90-213. The deployment of the spherical double probe antennas (SWDA) to 20 meters on each side began at 08:14:04 GMT and was completed at 08:47:06 GMT. For the next nine hours tests were run to determine the 20-meter SWDA characteristics over nearly a complete orbit. At approximately 8-minute intervals the Langmuir Probe Experiment switched the SWDA preamps between the Voltage and Current modes and carried out bias sweeps. When the SWDA was in the Voltage mode, the only significant interference was from the bias sweeps. When the SWDA was in the

Current mode, many interference lines were visible and the ones below 1 kHz were especially strong.

The deployment of the Fairchild long wire antennas (WADA) to 20 meters on each side began on Orbit 16 at 17:55:04 GMT on August 1, 1990, (day 90-213) and was completed at 18:20:20 GMT. The SFR and SA were both locked onto the WADA at 17:50 GMT and remained that way until 14:00 GMT on August 2, 1990, (day 90-214) during Orbit 18. The data showed very little interference except from a few power converters (and these lines were quite weak) and from the Langmuir Probe Experiment bias sweeps. For about the next nine hours tests were run to determine the 20-meter SWDA and 20-meter WADA characteristics over nearly a complete orbit. From 14:00 GMT on 90-214 until 23:15 GMT (Orbit 19) the SFR and SA were both commanded to their cycle modes. At approximately 8-minute intervals the Langmuir Probe Experiment again switched the SWDA preamps between the Voltage and Current modes and carried out bias sweeps. When the SWDA was in the Voltage mode, the only significant interference was from the bias sweeps. When the SWDA was in the Current mode, many interference lines were visible and the ones below 1 kHz were especially strong. A comparison of the WADA and SWDA data showed significant less sensitivity from SWDA above 10 kHz.

At 23:15 GMT on 90-214 the SFR and SA were both commanded to lock onto the WADA sensors and they remained in this state for approximately two full orbits until 19:16 GMT on August 3, 1990, (day 90-215) during Orbit 21. The only noticeable interference was from a few power converters (and these lines were very weak) and from the occasional Langmuir Probe Experiment bias sweeps. At 19:16 GMT on 90-215 the SFR and SA were both commanded to lock onto the SWDA sensors. They

remained in this state until just prior to the next WADA extension. No bias sweeping was done during this period until after the next SWDA extension and the only noticeable interference lines were at approximately 22 kHz and 66 kHz, the first and third harmonics of a power converter, and these were quite weak.

The deployment of the SWDA antennas from 20 meters to 35 meters on each side began on Orbit 22 on August 4, 1990, (day 90-216) at 04:43:47 GMT and was completed at 05:10:06 GMT. For the next nine hours tests were run to determine the 35-meter SWDA characteristics over nearly a complete orbit. At approximately 11-minute intervals the Langmuir Probe Experiment switched the SWDA preamps between the Voltage and Current modes and carried out bias sweeps. When the SWDA was in the Voltage mode, the only significant interference was from the bias sweeps. The 66 kHz power converter line was no longer visible and the 22 kHz power converter line was quite weak. When the SWDA was in the Current mode, many interference lines were visible and the ones below 1 kHz were still especially strong.

The deployment of the WADA antennas from 20 meters to 35 meters on each side began on Orbit 23 on the same day at 14:30:04 GMT and was completed at 14:50:11 GMT. At 14:22 GMT on 90-216 the SFR and SA were both commanded to lock onto the WADA sensors and they remained in this state until 01:43 GMT on August 5, 1990, (day 90-217) during Orbit 24. No bias sweeping was done during this period and the only noticeable interference were a few power converter lines which were extremely weak.

At 01:43 GMT on 90-217 the SFR and SA were both commanded to lock onto the SWDA sensors and they remained in this state until 11:00 GMT.

For about the next nine hours further tests were run to determine the 35-meter SWDA characteristics over nearly a complete orbit. For about the first eight minutes of each approximately 36-minute interval, the Langmuir Probe Experiment operated in the Current mode and then switched the SWDA preamps to the Voltage mode for the remainder of the interval. After about 03:20 GMT, they carried out nearly continuous bias sweeps. When the SWDA was in the Voltage mode, the only significant interference was from the bias sweeps except for the period 02:40 GMT to 03:20 GMT when the 22 kHz and 66 kHz power converter lines were moderately strong and many other lines from 100 Hz to 20 Hz were visible and the one near 100 Hz was very strong. When the SWDA was in the Current mode, many interference lines were visible but the ones below 1 kHz were much less apparent.

At 11:00 GMT on August 5, 1990, (90-217) during Orbit 25 the SFR and SA were both commanded to lock onto the WADA sensors and they remained in this state for approximately a full orbit until just before the final SWDA extension. No bias sweeping was done during this period and the only noticeable interference were a few power converter lines which were quite weak. The SFR and SA were both commanded to lock onto the SWDA sensors at about 21:08 GMT.

The deployment of the SWDA antennas from 35 meters to 50 meters on each side began on Orbit 26 on August 5, 1990, (day 90-217) at 21:07:52 GMT and was completed at 21:28:45 GMT. The SWDA antennas were actually stopped when the center of each sphere was 47 meters from the center of the spacecraft. The SWDA effective length thus is 94.0 meters, the distance between the center of the spheres. The "50 meters separation" actually applies to the tips of the stub booms which extend an

additional three meters on the outward side of each of the spheres but which do not provide any signals to the SWDA preamps. For about a nine-hour period after the extension was completed further tests were run to determine the 50-meter SWDA characteristics over nearly a complete orbit. At approximately 11-minute intervals the Langmuir Probe Experiment switched the SWDA preamps between the Voltage and Current modes and carried out bias sweeps. When the SWDA was in the Voltage mode, the only significant interference was from the bias sweeps. The 66 kHz power converter line was no longer visible and the 22 kHz power converter line was only moderately strong. When the SWDA was in the Current mode, many interference lines were visible and the ones below 1 kHz were still especially strong at low altitudes.

At 05:52 GMT on August 6, 1990, (90-218) during Orbit 27 the SFR and SA were both commanded to lock onto the WADA sensors just before the final WADA extension. The deployment of the WADA antennas from 35 meters to 50 meters on each side began at 06:04:32 GMT and was completed at 06:24:35 GMT. The tip of each WADA antenna is 50.0 meters from the center of the spacecraft (including the 1.3 meter distances from the center of the spacecraft to the outward edge of each WADA deployment mechanism). The effective length of the WADA antenna for AC signals is 50.0 meters, one half the tip-to-tip separation. The outer 10 meters of the stranded wire of the WADA antennas has no insulation over them. Thus, the effective length of the WADA antenna for DC signals is 90.0 meters, the separation distance between the centers of the uninsulated conductive portions of the WADA elements. No bias sweeping was done immediately after this full extension and the only

noticeable interference was from a few power converter lines which were quite weak.

At 02:30 GMT on August 7, 1990, (90-219) during Orbit 29 the SFR and SA were both commanded to lock onto the SWDA sensors and they remained in this state for approximately a full orbit. Except for a forty-minute period from 04:15 GMT to 04:55 GMT when the Current Mode was used, the Langmuir Probe Experiment was operated in the Voltage Mode. No bias sweeping was done. As before, many interference lines were observed in the Current mode and only a moderately intense 22 kHz line and a very weak 66 kHz line were observed in the Voltage mode.

At 12:22 GMT on 90-219 during Orbit 30, the SFR was commanded to the WADA sensors and the SA was commanded to cycle. At 21:35 GMT on 90-219 during Orbit 31, both the SFR and the SA were commanded to the Search Coil Magnetometer. At 08:05 GMT on August 8, 1990, (day 90-220) during Orbit 32, both the SFR the SA were commanded to cycle. At 17:31 GMT on 90-220 during Orbit 33, the SFR was commanded to the WADA sensors and the SA was commanded to cycle. At 03:20 GMT on August 9, 1990, (day 90-221) during Orbit 34, both the SFR the SA were commanded to the SWDA sensors. At 13:20 GMT on 90-221 during Orbit 34, the SFR was commanded to the WADA sensors and the SA was commanded to cycle. Except for special tests and periods affected by command anomalies and errors which are described later, this is the command state the experiment remained in for the remainder of the mission. The SFR was locked onto the long wire electric dipole antenna (WADA) and the SA cycled.

In order to compare the relative responses from the WADA and SWDA electric field sensors, for several test periods the inputs to the

CRRES Plasma Wave Experiment receivers were switched back and forth from one electric dipole system to the other every 160 seconds. The first such test period was from 06:13 GMT to 07:14 GMT on August 20, 1990, (day 90-232) on the inbound portion of Orbit 61. The second test period was from 08:18 GMT to 11:12 GMT on the same day during Orbit 62. The third test period was from 17:05 GMT to 18:58 GMT on August 22, 1990, (day 90-234) during the inbound portion of Orbit 67 and the outbound portion of Orbit 68. The fourth test period was from 00:23 GMT to 02:28 GMT on August 23, 1990, (day 90-235) on the inbound portion of Orbit 68. The fifth and final test period was from 05:23 GMT to 10:02 GMT on 90-235 during Orbit 69. From these tests and those done in between and following the various antenna extensions, we were able to determine that the WADA antennas and the electric preamps connected to them which were provided by The University of Iowa under the hardware contract are performing as desired over the frequency range from 5.6 Hz to 400 kHz.

The output from the SWDA preamps appears to be acceptable from 5.6 Hz up to a few tens of kHz. Above a few tens of kHz, the output from the SWDA preamps is significantly less than that from the WADA antenna and preamps. The precise amount of relative degradation will be determined in the future by detailed analyses of the data already collected when the inputs to the CRRES Plasma Wave Experiment receivers were switched back and forth from one electric dipole system to the other every 160 seconds and from the test data collected between and following the various antenna extensions. The results will be documented and provided to AFGL, UCB, and any other interested parties.

Several types of interference primarily at higher frequencies corresponding to various converter frequencies and/or clock lines have been observed in the CRRES Plasma Wave Experiment electric field data during the turn-on, initialization, checkout, and first chemical release campaign phases. Except for certain UCB/AFGL 701-14 modes which seriously contaminate the data we receive on WADA and/or SWDA, most of the interference is sufficiently weak that it does not significantly degrade our data. The UCB/AFGL 701-14 modes which frequently bias sweep either or both of the electric dipole antennas (SWDA and/or WADA) are particularly bad sources of interference to our instrument and should not be used except under the rarest of circumstances.

At very low frequencies, very low noise levels have been observed in the CRRES Plasma Wave Experiment data as compared to previous satellite experiments we have flown in the same region. The primary reason for this very pleasant result is that the entire CRRES solar array is continuously illuminated and that the solar array strings are not rotating into and out of sunlight.

The only major interference observed to date in the search coil magnetometer data after the magnetometer mast was extended are the emissions around 13 to 13.5 kHz (and harmonics thereof) generated by either AFGL 701-13-1 (the Fluxgate Magnetometer) or UCB/AFGL 701-14 (the Langmuir Probe) electronics which power the Fluxgate Magnetometer. In the SA data, this interference results in a relatively high noise level (Data Number > 45) for the 10 kHz magnetic channel.

The search coil magnetometer worked correctly and as desired over the frequency range from 5.6 Hz to 10 kHz from experiment turn-on until

March 30, 1991, at 06:12 GMT on Orbit 602. From that time on, the output of the search coil magnetometer remained fixed at the receiver noise level except for the very lowest frequency channels which had a continuously high noise level. The nature of the failure suggests that it was probably caused by a broken solder joint. We surmise that this was probably caused by excessive flexing due to the thermal cycling that occurred during the long shadow periods. Because our experiment was turned off during many of the long shadow periods due to spacecraft power problems, the search coil magnetometer was allowed to get very cold.

All of The University of Iowa/AFGL Plasma Wave Experiment flight hardware items flown on CRRES (except for the search coil magnetometer after Orbit 602) are operating perfectly and have produced truly outstanding quality data. The data from the Sweep Frequency Receiver (SFR) are especially impressive. The middle and top two bands of the SFR have two and four times, respectively, better temporal resolution than ISEE 1. Changing structure in the plasmaspheric and ionospheric densities to time scales of 8 seconds are frequently observed. New discoveries made possible with this instrumentation will be discussed later in this document.

After the experiment turn-on, initialization, and testing phases were completed, the CRRES Plasma Wave Experiment was operated in the command state such that the SFR was always locked onto the WADA sensors and the SA cycled. Several command anomalies occurred during the first year of operation that changed this command state. The first one occurred on September 26, 1990, (day 90-269) at 16:55:11 GMT during Orbit 153 when the SFR and SA both switched to being locked on to the

SWDA sensors. The instrument was commanded back to the correct state at 10:01 GMT on September 27, 1990, (day 90-270) during Orbit 154.

The second command anomaly occurred on October 27, 1990, (day 90-300) at 13:47 GMT during Orbit 228 when CSTC commanded the experiment off because they erroneously thought the power supply parameters were out of specification. The reason for this error was that CSTC was monitoring our data in the wrong format (in the LASSII Format instead of in the GTO Format). The experiment was commanded back on at 16:40 GMT on 90-300.

The third command anomaly occurred on November 15, 1990, (day 90-319) at 14:07:40 GMT during Orbit 274. The SFR switched to being locked onto the SWDA sensors. The SA remained cycling. The instrument was commanded back to the correct state at 09:36 GMT on November 17, 1990, (day 90-321) during Orbit 278.

The fourth command anomaly occurred on December 14, 1990, (day 90-348) during Orbit 344. The experiment was commanded off at 03:40 GMT in order to conserve power because of spacecraft battery problems and the beginning of the long shadow periods. When the experiment was commanded back on at 05:31 GMT, it was commanded to have both the SFR and SA cycle. It was finally commanded to the correct mode at 21:00 GMT on December 15, 1990, (day 90-349) during Orbit 348.

The fifth command anomaly occurred on March 26, 1991, (day 91-085) at 04:44:12 GMT during Orbit 592. Both the SFR and the SA switched to being locked onto the SWDA sensors. The experiment was commanded to the correct mode at 07:46 GMT on 91-085 during Orbit 593.

The sixth command anomaly during the first year of operation occurred on March 26, 1991, (day 91-087) at 08:39:40 GMT during Orbit

598. The SFR switched to being locked onto the SWDA sensors. The experiment was commanded to the correct state at 14:04 GMT on 91-087 during Orbit 598.

The majority of these command anomalies occurred at times when other experiments and spacecraft systems experienced anomalies. It is believed that electrical discharges within or near the spacecraft were affecting the command system.

The CRRES spacecraft transmits no Plasma Wave Experiment data in the LASSII Format. Thus we do not receive data during LASSII tests or during periods on every other or every fourth orbit near perigee when the spacecraft is in the LASSII Format.

3. PROGRESS AND CURRENT ACTIVITIES

In this section we will describe the activities that have been carried out and the progress that has been made for the first year under this contract. First we will address the development of algorithms to derive key parameters useful for analyzing the CRRES data. In the second part we will discuss the development of statistical and event studies. In the final part of this section we will discuss the initial results and new discoveries made with the CRRES Plasma Wave Experiment data.

3.1 Development of Algorithms to Derive Key Parameters Useful for Analyzing CRRES Data

The goal of deriving Key Parameters from the CRRES Plasma Wave Experiment data depends heavily on the determination of the two most important characteristic frequencies of the plasma, the plasma frequency (F_p) and the cyclotron frequency (F_c), from which all the other important characteristic frequencies are dependent and can be calculated. The electron cyclotron frequency is calculated directly from the magnitude of the measured ambient magnetic field ($|B|$) detected by the Fluxgate Magnetometer Experiment: $F_{ce} = 0.028 \text{ kHz} \times |B|$ measured in nT (nanoTesla). Determining the electron plasma frequency is equivalent to determining the electron number density (N_e) as a function of time: $F_{pe} = 8.98 \text{ kHz} \times N_e^{1/2}$ where N_e is in electrons per cubic centimeter (cm^{-3}). The plan of approach for using the CRRES Plasma Wave Experiment data to determine the electron number density was based on the past vast experience at the University of Iowa with analyzing the Sweep Frequency Receiver data from ISEE-1 and DE-1 in order to obtain magnetospheric electron number densities. This

experience lead us to correctly predict that for a large majority of the time throughout the CRRES GTO orbit emissions at the Upper Hybrid Resonance (UHR) frequency or cutoffs at the electron plasma frequency would be sufficiently detectable and identifiable in the CRRES Sweep Frequency Receiver data that the electron number density can be determined. From those points identified as the electron plasma frequency, the electron number density is derived directly from the relationship shown above. From those points identified as the UHR frequency, one must first determine the electron plasma frequency from the measured UHR frequency (F_{UHR}) and the calculated electron cyclotron frequency F_{ce} using the relationship $(F_{UHR})^2 = F_{ce}^2 + F_{pe}^2$.

About half of our effort for the first two calendar years of this contract according to the proposal for which this contract was awarded was to be spent on developing an automatic computer program for determining the electron number density. The first step in the plan was to use our in-house ISEE 1 data acquired in regions through which CRRES passed to develop and test the automatic program because the ISEE 1 receiver was similar to the one on CRRES and the data were already available. Upon receipt of our agency tape data, we were then going to process the tapes and produce files from which either hardcopy or video spectrograms of the sweep frequency receiver data could be produced. We were also going to process the data on the computer to automatically extract the electron number density. The results were going to be compared with the spectrograms to see if the number density had been correctly determined. If the automatically produced number density profiles were questionable, the data for the periods in question would be processed using manual intervention. When manual intervention was

required, technicians under the supervision of the Principal Investigator were to display the spectrograms on an interactive computer terminal and then trace, identify, and label the appropriate frequency step on each sweep of the spectrogram that corresponds to either the UHR frequency or the electron plasma frequency.

Once the electron number densities had been determined, they along with a quality indicator and a time tag were to be transferred via the SPAN (Space Physics Analysis Network) network back to AFGL for inclusion as one of the key parameters in the environmental data base essential for the long term modeling studies and also useful for helping other investigators understand and interpret their data.

This plan could not be fully carried out as planned for several reasons. One was that because this contract was awarded less than three months before CRRES was launched, there was insufficient time to test and develop algorithms for the automatic extraction of the electron number density using the ISEE 1 data. Another reason is that even though within the plasmasphere the UHR emission lines are usually quite strong and clear, outside the plasmasphere the emissions associated with the upper hybrid resonance frequency or the electron plasma frequency are occasionally weak and frequently very close to other emissions or difficult to distinguish without the understanding of someone who has had sufficient experience in interpreting the data. In order to extract the number density data in the most efficient and timely manner given these considerations, we chose to carry out the first steps in the number density extraction process manually. Research aides and technicians under the supervision of the scientific investigators display the spectrograms on interactive computer

terminals and then trace, identify, and label the appropriate frequency step on each sweep of the spectrogram that corresponds to either the UHR frequency or the electron plasma frequency. These data are then processed by a computer program which takes this input along with the measured magnetic field data and then calculates and outputs as a function of time the electron number density, electron plasma frequency, electron cyclotron frequency, upper hybrid resonance frequency, and a marker identifying the source as being either the plasma frequency or the UHR frequency. The files are merged into one file per orbit. The merged files are then copied onto diskettes and mailed to AFGL per their request.

Since the beginning of the contract was less than three months before launch, the initial programming effort was aimed at producing data displays of the CRRES Plasma Wave Experiment data that would satisfy the requirements for checking the experiment out after launch, to provide real-time displays both at CSTC and at The University of Iowa, and to provide hardcopy and disk-file output that could be used for the number density extraction, event studies, and other data analysis requirements.

The University of Iowa purchased two DEC VAXstation 3100 computers for use on the CRRES data reduction and analyses activities using cost-sharing funds provided by the University. One of these was used at CSTC for the experiment turn-on, initialization, and testing activities. Following these activities, this computer remained at CSTC in order to provide near-real-time monitoring of the CRRES Plasma Wave Experiment and to support the CRRES chemical release activities. The near-real-time monitoring was important to insure that command

anomalies and operations that interfered with our experiment were corrected or ceased as soon as possible to minimize the impact on our ability to collect high quality data.

Examples of the type of data display generated for the CRRES Plasma Wave Experiment for use in the extraction of the electron number density data as well as for event studies are shown in Figures 1 and 2. Figure 1 shows the first data we have on the outbound portion of Orbit 73 on August 24, 1990 from about 20:00 UT to about 21:45 UT and Figure 2 shows the data from about 21:45 UT to about 23:35 UT. These color spectrograms include data from both the Sweep Frequency Receiver (SFR) (100 Hz to 400 kHz) and from the lower 6 channels of the Spectrum Analyzer (SA) (5.6 Hz to 100 Hz). The logarithmic vertical scale along the ordinate is frequency measured in Hz from 5 Hz to 400 kHz. The three horizontal ticks on the left and right sides of the plots indicate the separation frequencies (800 Hz, 6.4 kHz, and 50 kHz) between the four SFR bands. To convert the vertical scale from frequency to electron number density (N_e), one divides the emission frequency (either Plasma Frequency or Upper Hybrid Resonance Frequency) by 8.98 kHz and squares the result. The answer will be in particles/cm³. Thus a plasma frequency (F_p) of 8.98 kHz indicates $N_e = 1.0 \text{ cm}^{-3}$ while a F_p of 89.8 kHz indicates $N_e = 100 \text{ cm}^{-3}$. The maximum SFR frequency, 399 kHz, corresponds to $N_e = 1974 \text{ cm}^{-3}$.

The linear horizontal scale along the abscissa is Universal Time. The CRRES spacecraft orbit parameters printed below the time labels include the geocentric distance to the spacecraft in Earth Radii, geomagnetic latitude, magnetic local time, the McIlwain L value, and F_{ce} . The time widths of the plots shown here are approximately 1.82



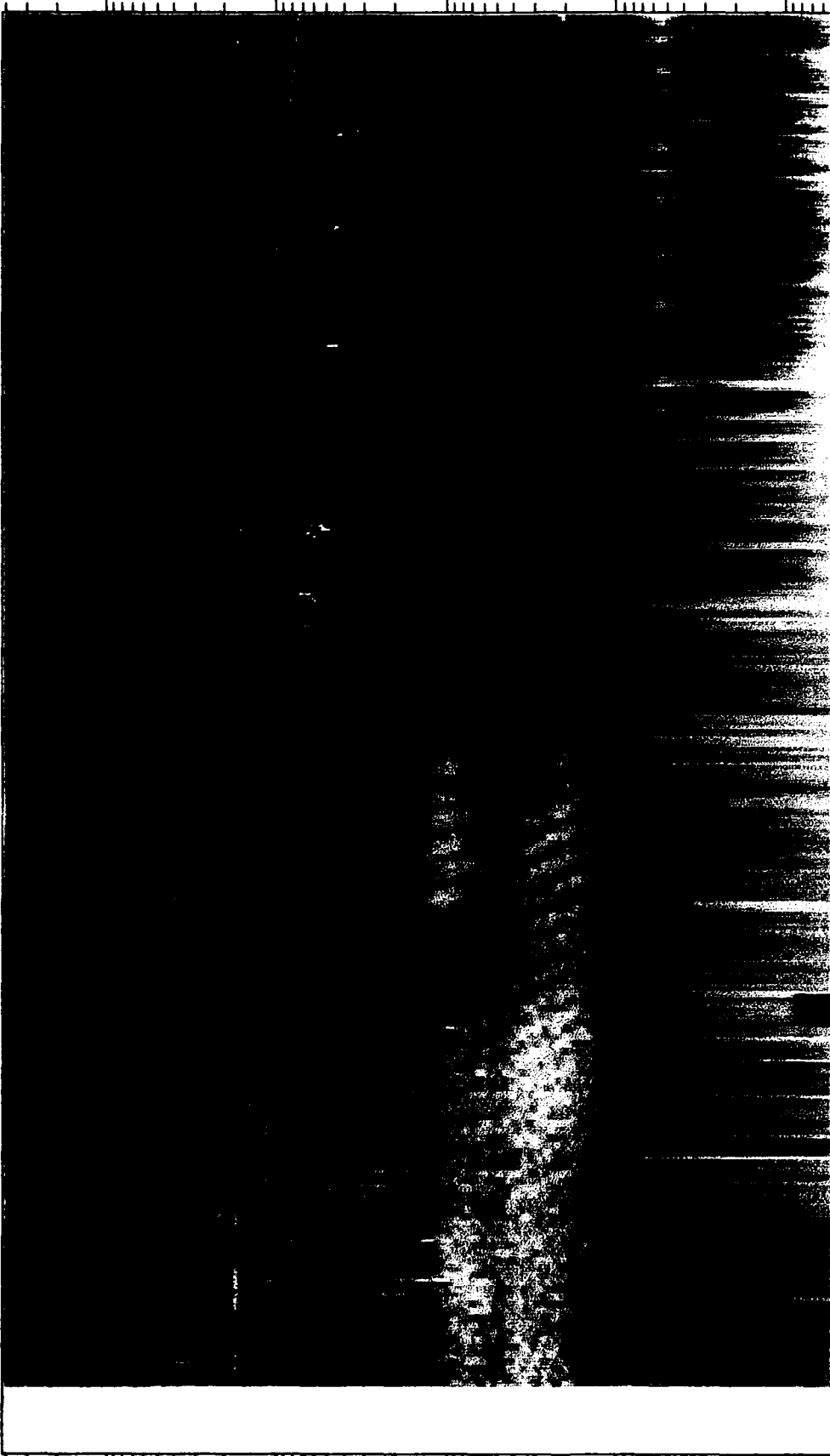
CRRES SFR/SA

dBV/m/√Hz

-160.0

-66.0

0073 AUG. 24, 1990 (90-236 19:55:27)



UT (HH:MM)
R (RE)
MAG LAT
MLT (HRS)
L
FCE (KHz)

20:00	20:20	20:40	21:00	21:20	21:40
1.48	2.25	2.96	3.57	4.10	4.55
-23.04°	-19.37°	-15.06°	-11.87°	-9.46°	-7.56°
23.70	2.16	3.31	4.01	4.52	4.90
1.76	2.46	3.12	3.71	4.23	4.67
315.75	90.80	37.06	19.92	12.59	8.93



Figure 1

01383800

hours each. The label on the left side of the plots indicates the Orbit number, date, and Universal Time at the beginning of the plots. The color bar at the top of the plots identifies the calibrated electric field strength. The colored line at the bottom of the plots show the SFR antenna selection status.

The five minute data gap at the beginning of the first plot is due to the spacecraft being in the LASSII mode at that time. The white line beginning at the top left corner indicates the position of the electron cyclotron frequency as calculated from the Fluxgate Magnetometer data included on the Agency tapes. The glitches in the 5.6 Hz and 56 Hz SA data and the gap in the F_{ce} line just before 20:30 UT in the first plot are due to the Spacecraft being in the CSM (Command Storage Memory) mode for that interval. Those three items are among the data lost in the CSM mode.

The UHR emission line is clear in Figure 1 from about 20:15 UT when it comes into the frequency range of the SFR until the outer edge of the plasmasphere is reached at about 21:00 UT. Figures 1 and 2 show that outside of the plasmasphere several electron cyclotron harmonic (ECH) lines (also called $n+1/2 F_{ce}$ emissions) as well as trapped continuum emissions are evident which make the electron number density extraction more difficult. From our experience we would locate the plasma frequency above the highest ECH line and below the continuum. Figures 3 and 4 show the results of the number density extraction for the data shown in Figures 1 and 2. Each plot contains three lines from top to bottom: F_{UHR} , F_{pe} , and F_{ce} . (Only in the rarest of circumstances does F_{ce} ever exceed F_{pe} in the portion of the CRRES orbit where we can determine the electron number density.) When F_{pe} is



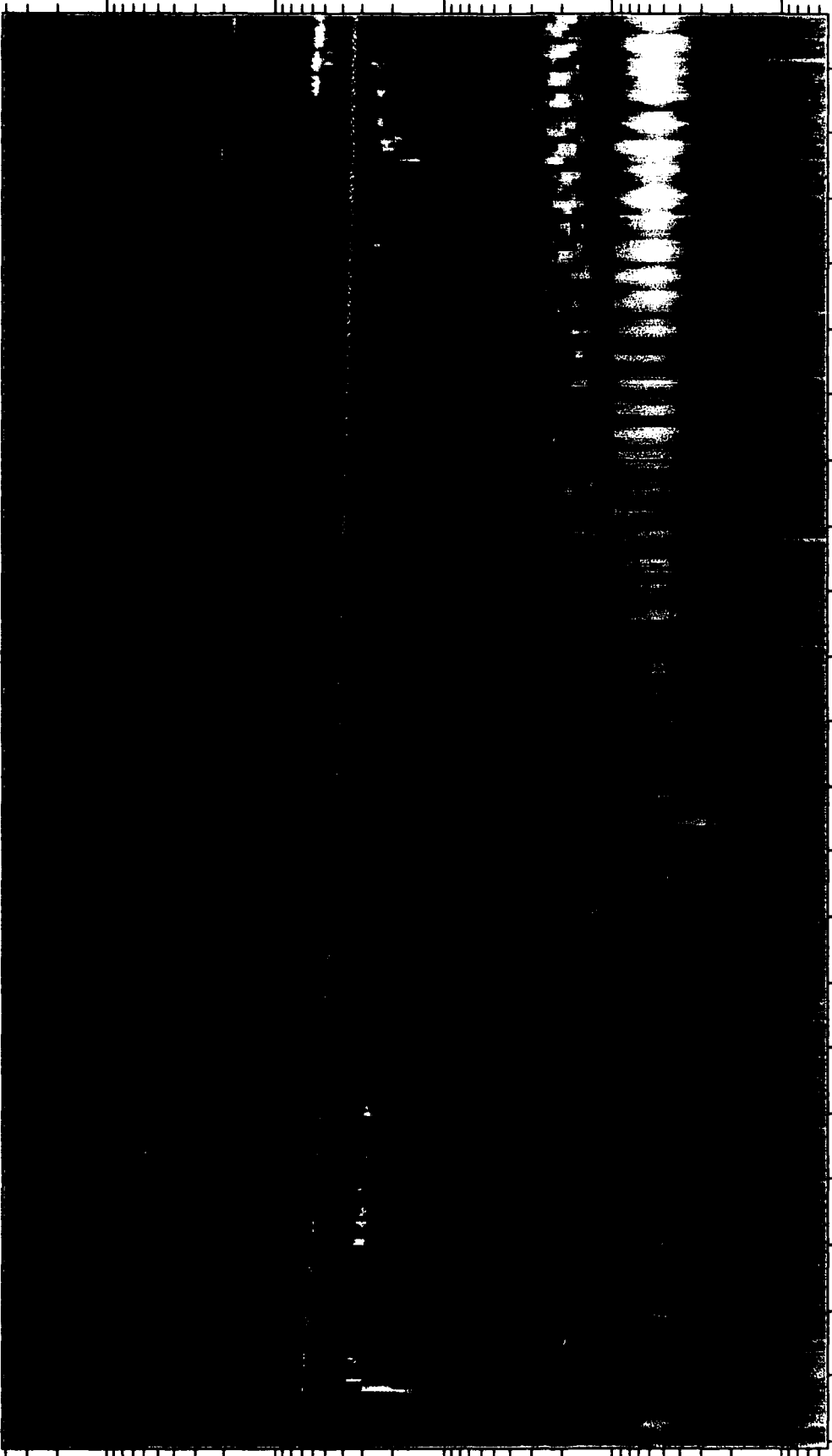
CRRES SFR/SA

dBV/m/ $\sqrt{\text{Hz}}$

-166.0

-66.0

0073 AUG. 24, 1990 (90-236 21:44:40)



UT (HH:MM)
R (RE)
MAG LAT
MLT (HRS)
FCE (KHZ)

21:50
4.75
-6.75°
5.07
4.87
7.77

22:10
5.11
-5.32°
5.37
5.21
6.18

22:30
5.41
-4.08°
5.63
5.50
5.17

22:50
5.67
-2.98°
5.87
5.74
4.51

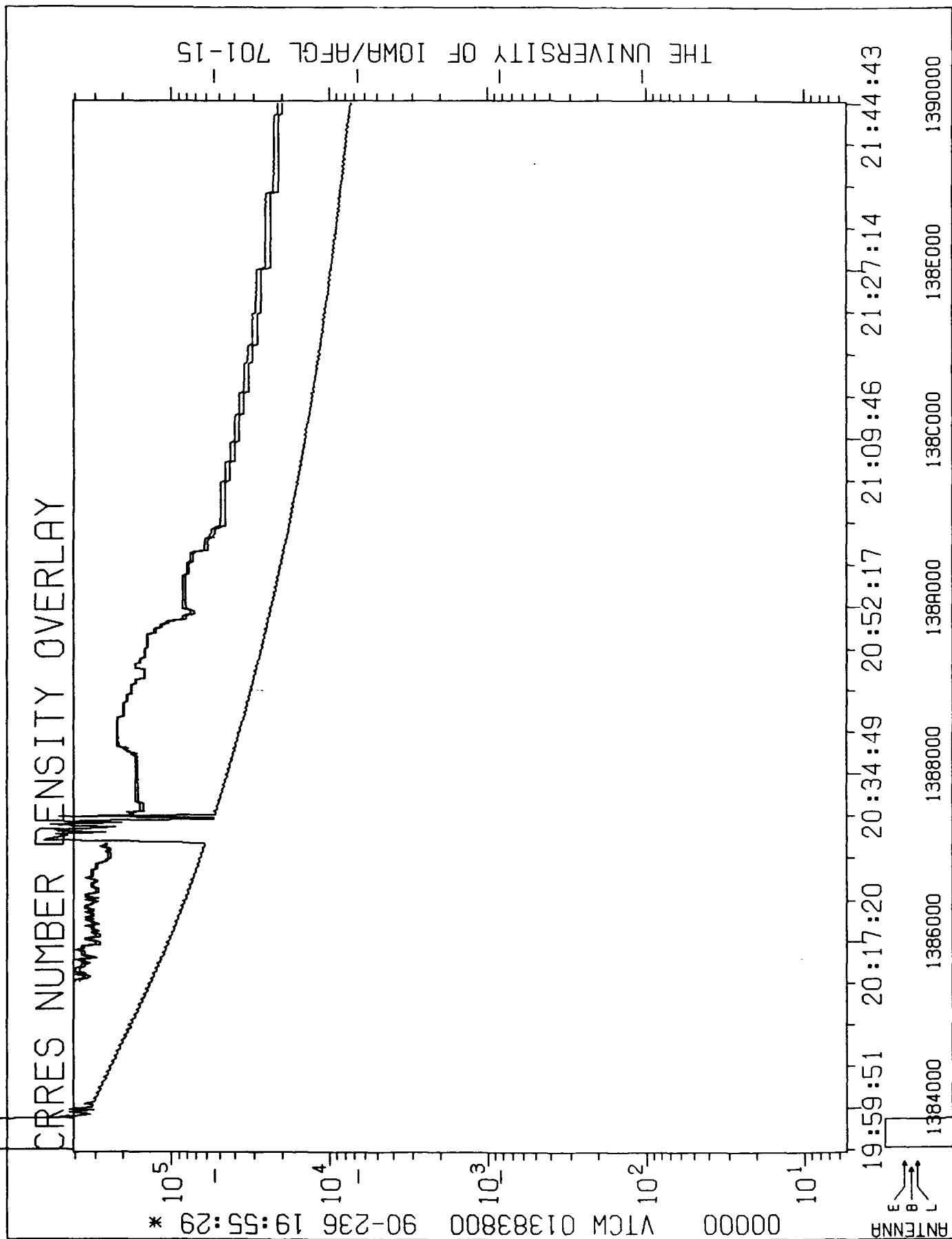
23:10
5.87
-1.98°
6.08
5.94
4.06

23:30
6.03
-1.06°
6.29
6.09
3.76



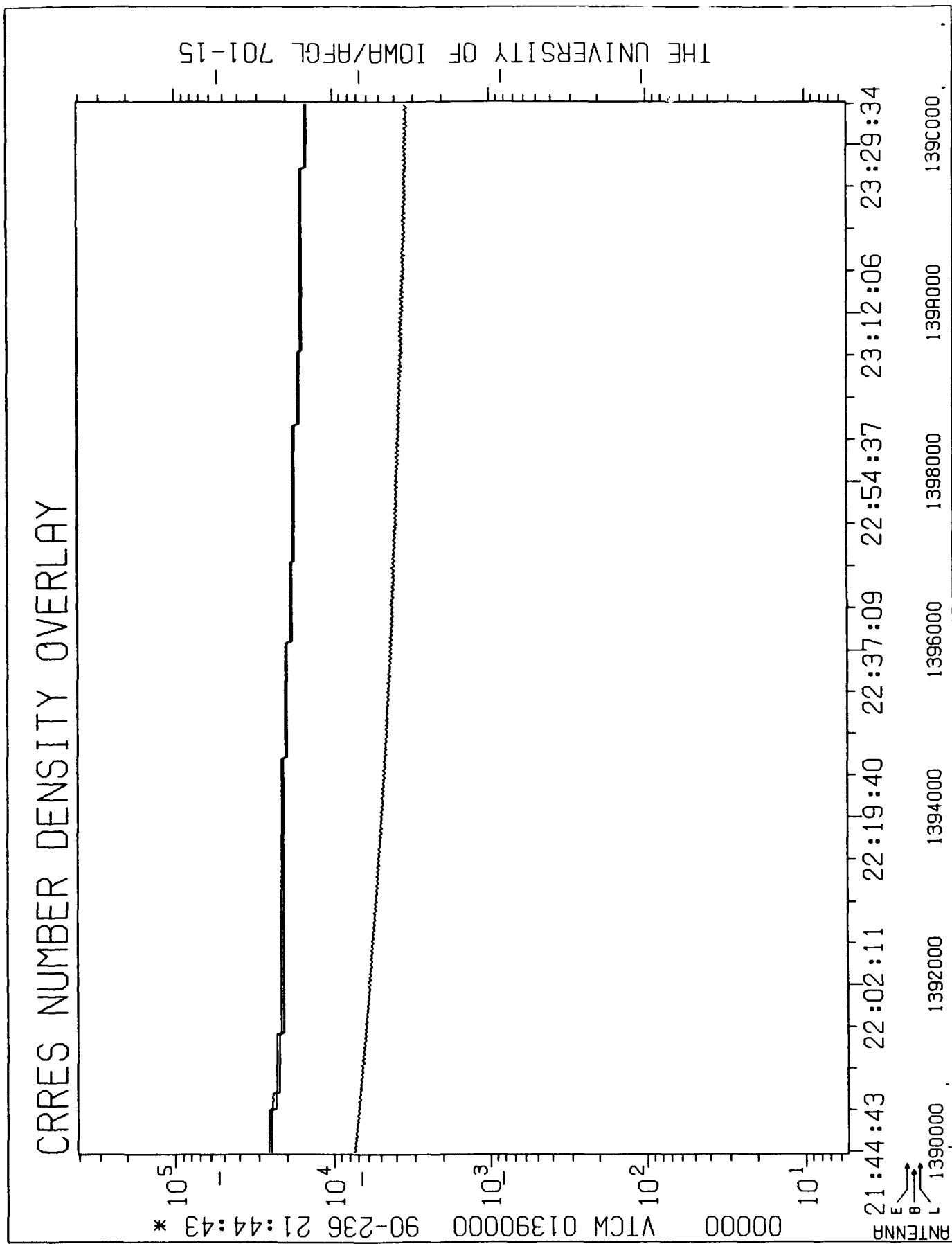
Figure 2

01390000



THE UNIVERSITY OF IOWA/AFGL 701-15

Figure 3



much larger than F_{ce} as is usually the case for much of the inside of the plasmasphere, F_{UHR} and F_{pe} are nearly identical when plotted on logarithmic scales. One of the important findings coming out of the CRRES data and well illustrated in these examples is the large amount of structure in the number density profiles both inside and outside the plasmasphere.

3.2 Development of Statistical and Event Studies

Using the techniques described above we have completed the electron number density extraction from approximately 140 orbits and are continuing the extraction from the remaining orbits. In addition to providing the extracted data to AFGL, The University of Iowa scientists, graduate students, and undergraduate Honors students are carrying out several research projects whose primary objectives are understanding and interpreting the electron number density data statistically in order to provide models of electron number density profiles throughout the inner magnetosphere traversed by CRRES. These studies include determining long term average plasma densities as a function of location and geomagnetic conditions and determining average plasmopause locations as a function of local time and geomagnetic conditions. Other statistical studies to be carried out in the future such as how the intensities of various plasma wave modes vary as a function of location, geomagnetic conditions, and other parameters such as plasma density will be discussed in Section 4.

A number of event studies using the CRRES Plasma Wave Experiment data are in progress. Some involve the electron number density measurements available from CRRES and others are primarily concerned with wave-particle interactions. One of the outstanding features in

the CRRES PWE data is the detection of very high degrees of fluctuations in the plasma density. An example of this is shown in Figure 5 which is on the inbound portion of Orbit 143 On September 22, 1990 (day 90-265). Figure 5 shows the CRRES PWE data from about 21:30 UT to about 23:20 UT. Large quasi-periodic fluctuations in the plasma density are evident from the fluctuating UHR emissions observed just after the plasmopause crossing at about 22:24 UT. Noticeable fluctuations are observed deep into the plasmasphere. Such fluctuations have been detected on many orbits. Michael LeDocq, a graduate student, is studying these fluctuations for his thesis work. He is Fourier analyzing the density fluctuations to see how the intensity and spectra of the fluctuations change with location and local time.

The data shown in Figure 5 also illustrate a number of interesting features involved in some of the wave-particle interaction studies we are carrying out. An intense band of chorus is observed centered at about 2 kHz at the beginning of the plot and rising to about 8 kHz at the plasmopause. In this example the chorus penetrates a short distance into the plasmasphere. One of our studies is aimed at understanding what determines whether or not and how far the chorus penetrates into the plasmasphere. From about 21:50 to 22:06, the lower cutoff of the chorus drops dramatically from a few kHz down to several hundred Hz. We would expect to find a higher energy population of electrons to be associated with these lower frequency whistler-mode emissions than those associated with the main band of whistler-mode emissions. A low frequency hiss band (also believed to be in the whistler-mode) centered around 100 Hz begins about 21:50 and becomes



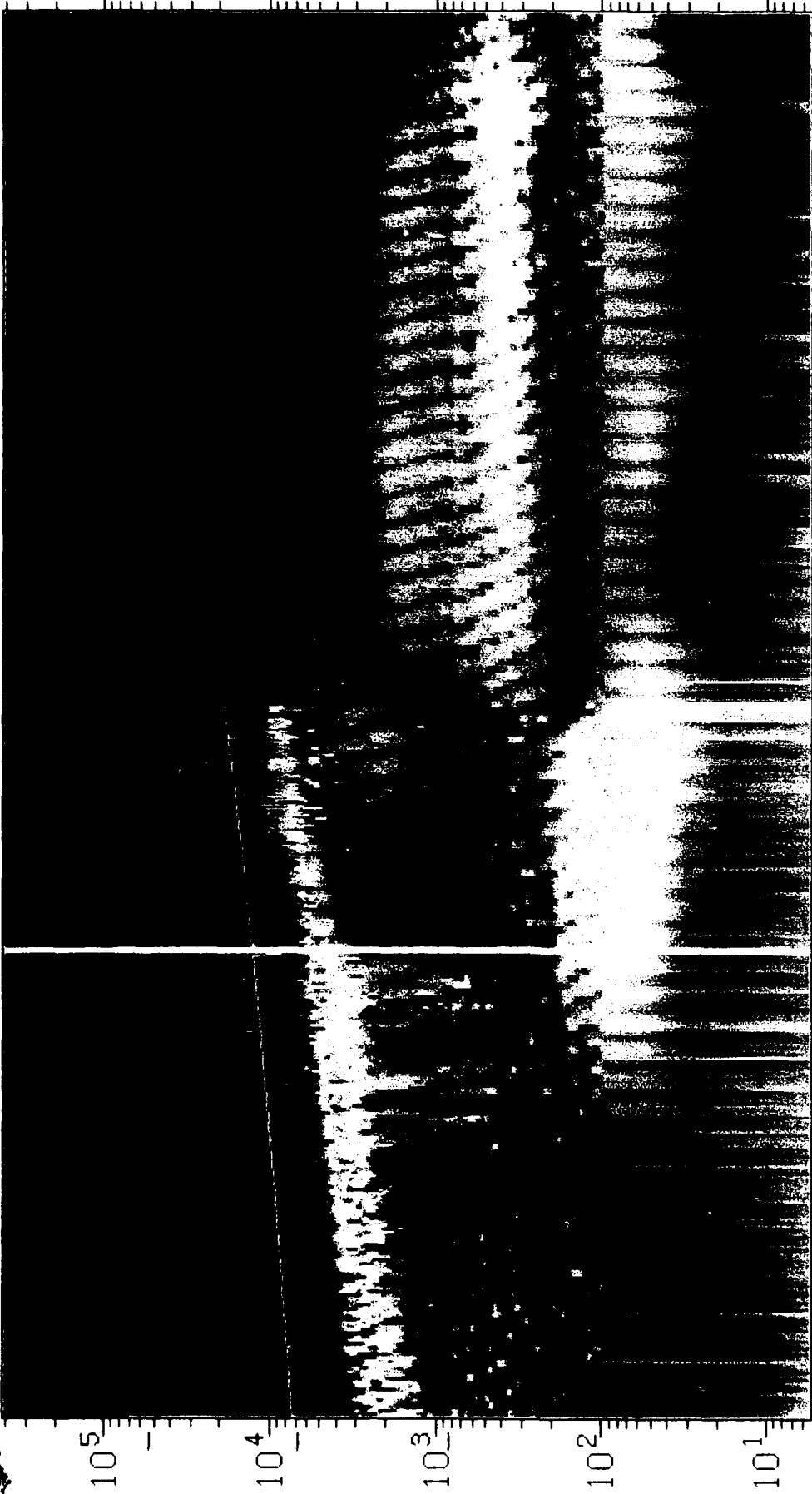
CRRES SFR/SA

dBV/m/ $\sqrt{\text{Hz}}$

-166.0

-66.0

0143 SEP. 22, 1990 (90-265 21:30:20)



UT (HH:MM)	21:40	22:00	22:20	22:40	23:00
R (RE)	4.70	4.27	3.78	3.20	2.53
MAG LAT	10.10°	9.99°	9.74°	9.24°	8.14°
MLT (HRS)	7.78	8.18	8.66	9.31	10.27
L	4.86	4.40	3.86	3.23	2.52
FCE (KHZ)	8.51	11.40	16.70	27.86	56.78



Figure 5

most intense just before the plasmopause crossing. We would expect an even higher energy band of electrons to be associated with this hiss band. A phenomena commonly observed in the CRRES data but not yet understood is the enhanced low-frequency electric field emissions from 5 Hz to 100 Hz beginning right at the plasmopause and lasting for about two minutes. Multiple hiss bands are evident within the plasmasphere. A question we are studying is whether or not any of them have any relation to the emissions outside the plasmasphere. The data in Figure 5 also clearly show how emission lines making up the "continuum" radiation can emanate from the steep density gradients at the plasma pause out into the low density regions.

Figure 6 is a two-hour plot of the CRRES electric field data on the outbound portion of Orbit 46 on August 13, 1990, (day 90-225) from 18:00 UT to 20:00 UT. The plasmopause shown here is more classic than those shown previously but still the density profiles show a fair amount of structure. In this example the chorus emissions penetrate deeper into the plasmasphere than before. Figures 7 and 8 are plots of the 5.6 Hz to 10 kHz Spectrum Analyzer data for the electric and magnetic sensors, respectively. Comparison of these plots allows us to distinguish electromagnetic emissions (which appear in both plots) from electrostatic emissions (which appear only in the electric field plots). The low frequency emissions appearing around 18:40 UT right at the plasmopause are seen to be clearly electrostatic. The glitches beginning at about 18:15 UT are when the spacecraft was in the CSM Format and the four channels (5.6 Hz, 56.2 Hz, 562 Hz, and 5.62 kHz) contain meaningless data.

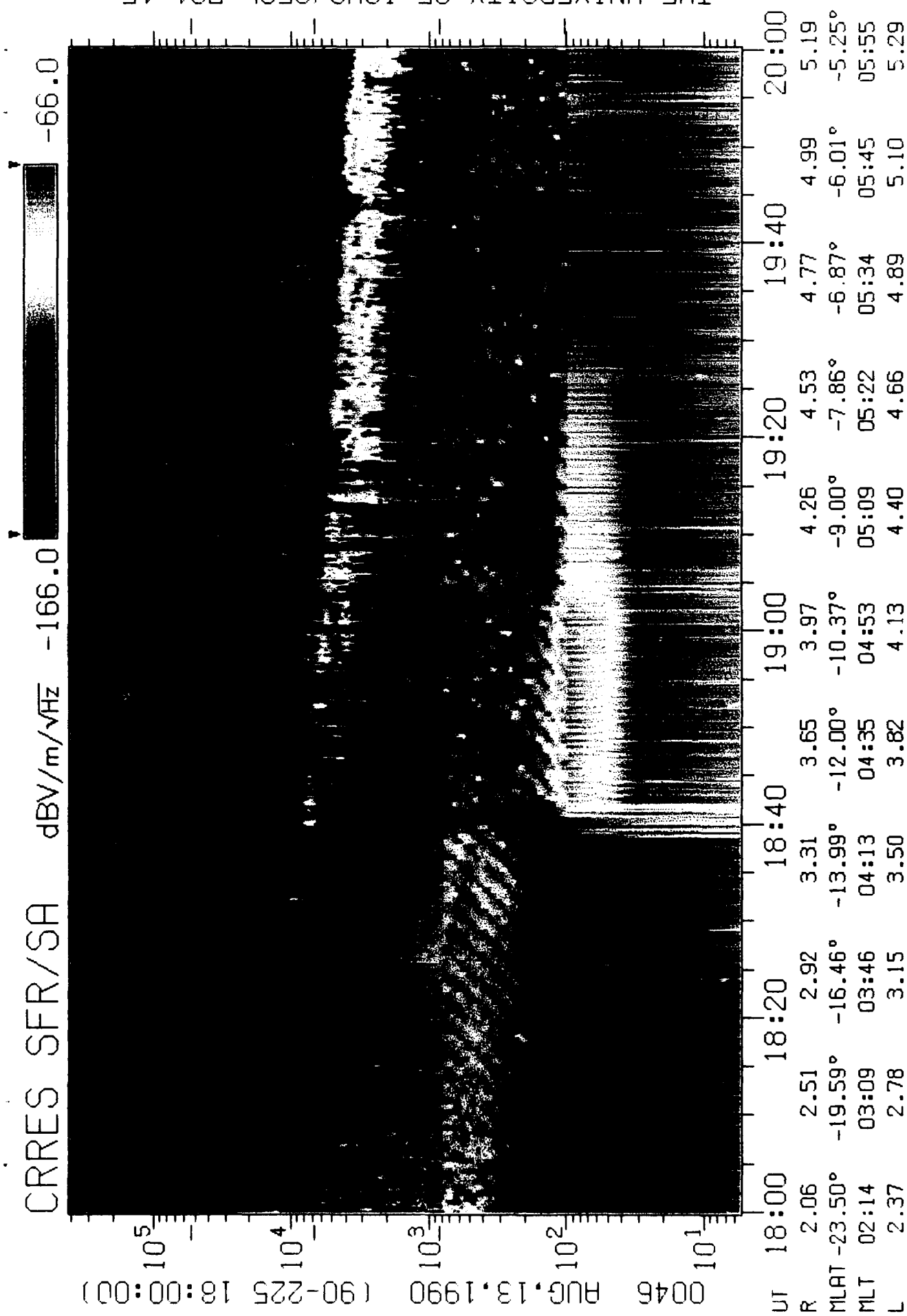
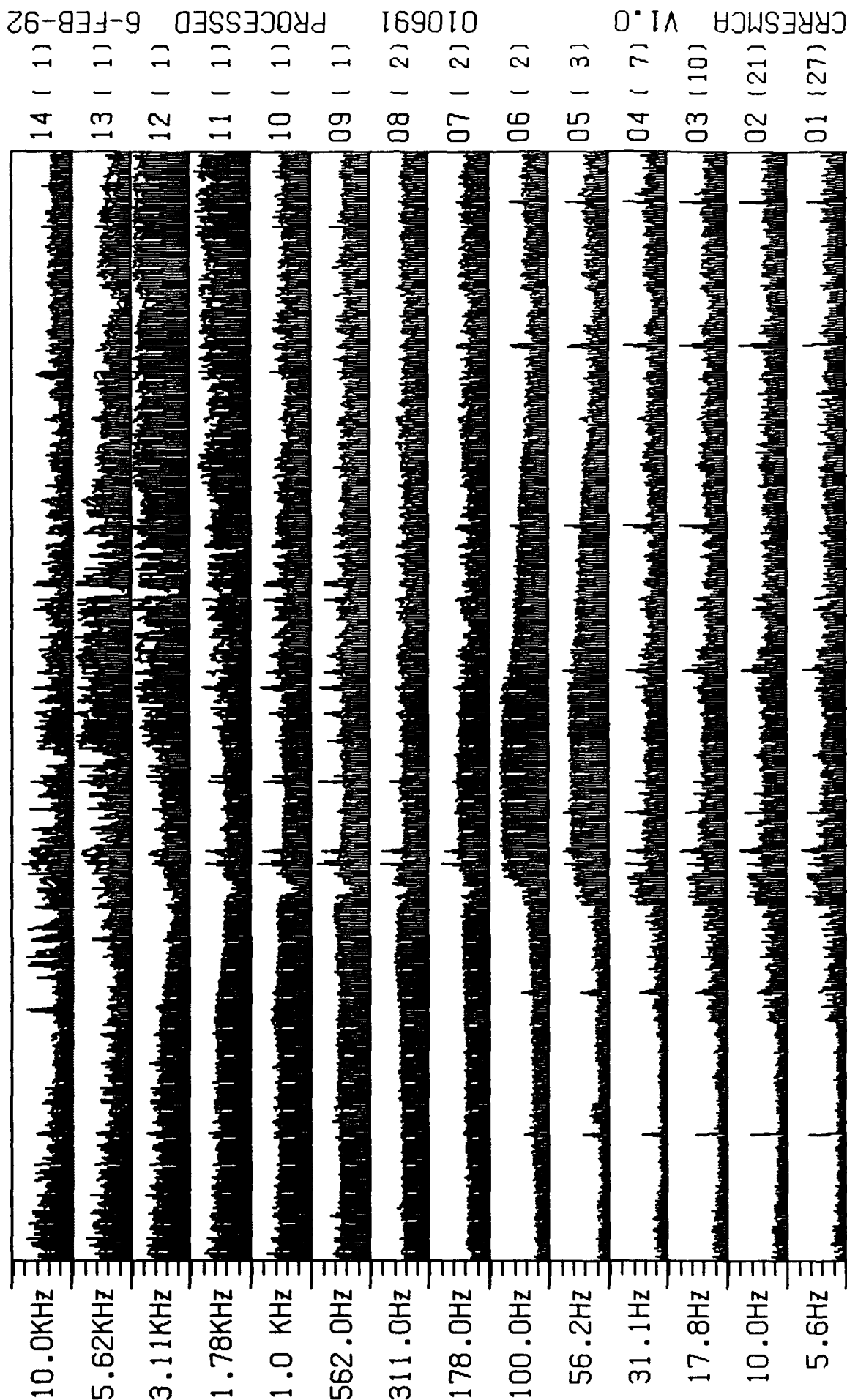


Figure 6

CRRES MCA AUG.13,1990 (90-225) 18:00:00

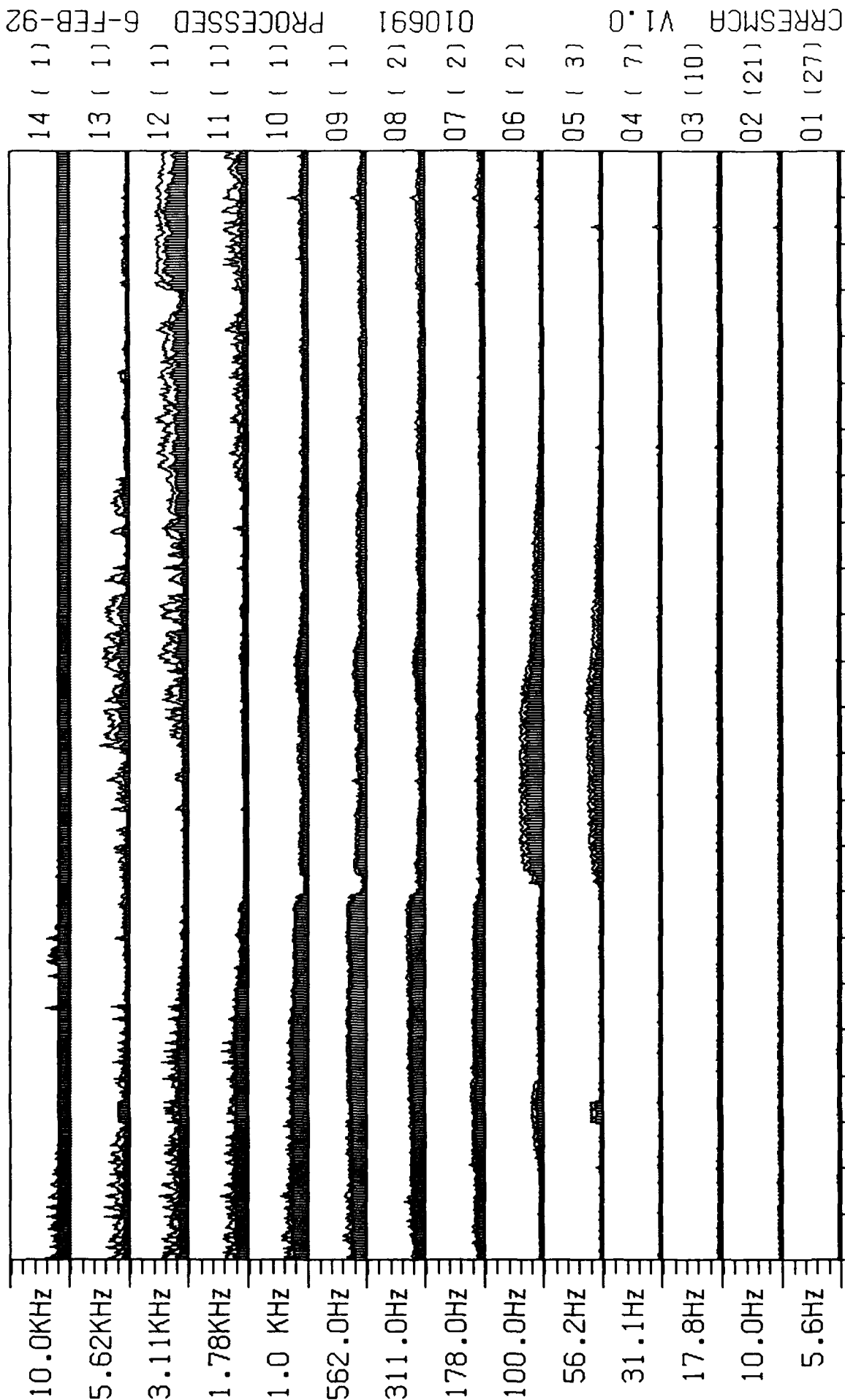
ORBIT 00046 ELEC ANTENNA 2 HR



18:00:00 18:20:00 18:40:00 19:00:00 19:20:00 19:40:00 20:00:00

CRRES MCA AUG, 13, 1990 (90-225) 18:00:00

ORBIT 00046 MAG ANTENNA 2 HR



00C61871

Figure 8

Figure 9 is a two-hour color spectrogram from Orbit 46 taken from 20:30 UT to 22:30 UT near apogee. The intense multiple bands of emissions from about 21:05 UT to about 21:45 UT are Electron Cyclotron Harmonic (ECH) emissions. Past studies have shown them to be most intense near the geomagnetic equator. The geomagnetic equator crossing is at about 22:10 UT. Some people have speculated that possibly the ECH emissions might be an indicator of the actual geomagnetic equator and that other derivations of its location might have modeling induced errors. However this illustration shows that the minimum in the ambient magnetic field (indicated by minimum in the location of the red lines which are drawn at the electron cyclotron frequency and its harmonics) occurs at 22:10 UT in agreement with the geomagnetic latitude from the orbit parameters. These ECH emissions clearly occur a short distance away from the geomagnetic equator. One of the event studies we are presently working on is to identify the characteristics of the particle populations that are associated with the ECH emissions. Chris Paranicas at Boston University has lead several statistical studies of the characteristics of the ECH emissions observed in the CRRES data. Among the items included in these studies were the frequency of occurrence of the ECH emissions with respect to magnetic latitude and local time and the relative location in frequency within a harmonic band of the peak emission intensity.

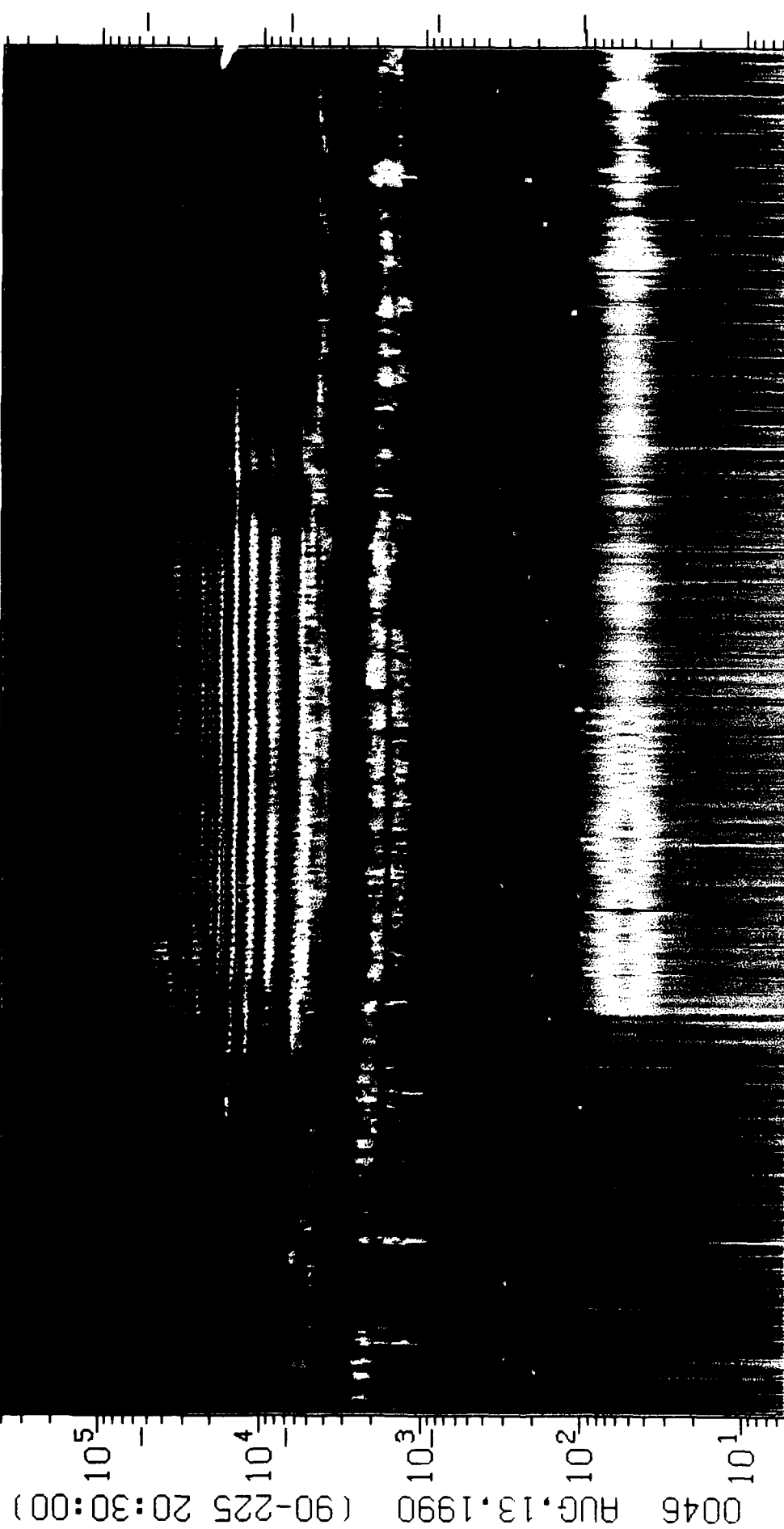
Figure 10 is a two-hour color spectrogram from the inbound portion of Orbit 46 taken from 00:20 UT to 02:20 UT on August 14, 1990, (day 90-226). Numerous event and statistical studies are underway using the data from this and other similar spectrograms. Several plasmopause crossing features are evident from 01:28 UT to 01:42 UT. The abrupt

CRRES SFR/SA

dBV/m/√Hz

-166.0

-66.0



UT 20:30

R 5.61

MLAT -3.68°

MLT 06:18

L 5.68

20:50

5.74

-3.15°

06:26

5.81

21:10

5.97

-2.20°

06:41

6.01

21:30

6.13

-1.36°

06:55

6.16

21:50

6.19

-0.97°

07:02

6.21

22:10

6.26

-0.22°

07:16

6.27

22:30

6.27

0.14°

07:22

6.27

0.50°

07:29

6.27

0046 AUG. 13, 1990 (90-225 20:30:00)

Figure 9

rise in density at 01:28 UT coincides with the cessation of the ECH emissions and an intense burst of very low frequency (< 100 Hz) emissions. The local minimum in plasma density around 01:33 UT coincides with another burst of very low frequency emissions and is also the point where the plasmaspheric hiss band begins to increase in intensity. The small but very steep jump in density at 01:42 UT coincides with a weaker enhancement in the very low frequency emissions and a further intensification in the plasmaspheric hiss band. Janet McLarty, an undergraduate Honors student, is studying the location and characteristics of plasmopause crossings as a part of her Honors research. The high degree of variability in the types of plasmapauses is evident by comparing those shown here with those observed in Figures 1, 5, and 6.

A graduate student, Allen Kistler, is studying "continuum" storms which are sudden enhancements in the continuum radiation observed outside the plasmasphere. In Figure 10, the continuum radiation is made up of the numerous approximately horizontal (nearly constant in frequency) emission lines from about 50 kHz down to the plasma frequency cutoff which occurs at about just above the third ECH emission line. He is studying the morphology of the "continuum" storms and trying to identify the particle population associated with their generation or enhancements.

The two bursts of emissions around 00:40 UT and 01:05 UT which consist of many nearly vertical lines from about 40 kHz to about 80 kHz are auroral kilometric radiation (AKR). This radiation is generated in the auroral zones near the local electron cyclotron frequency and much of it is prevented from being detected by CRRES by the high density

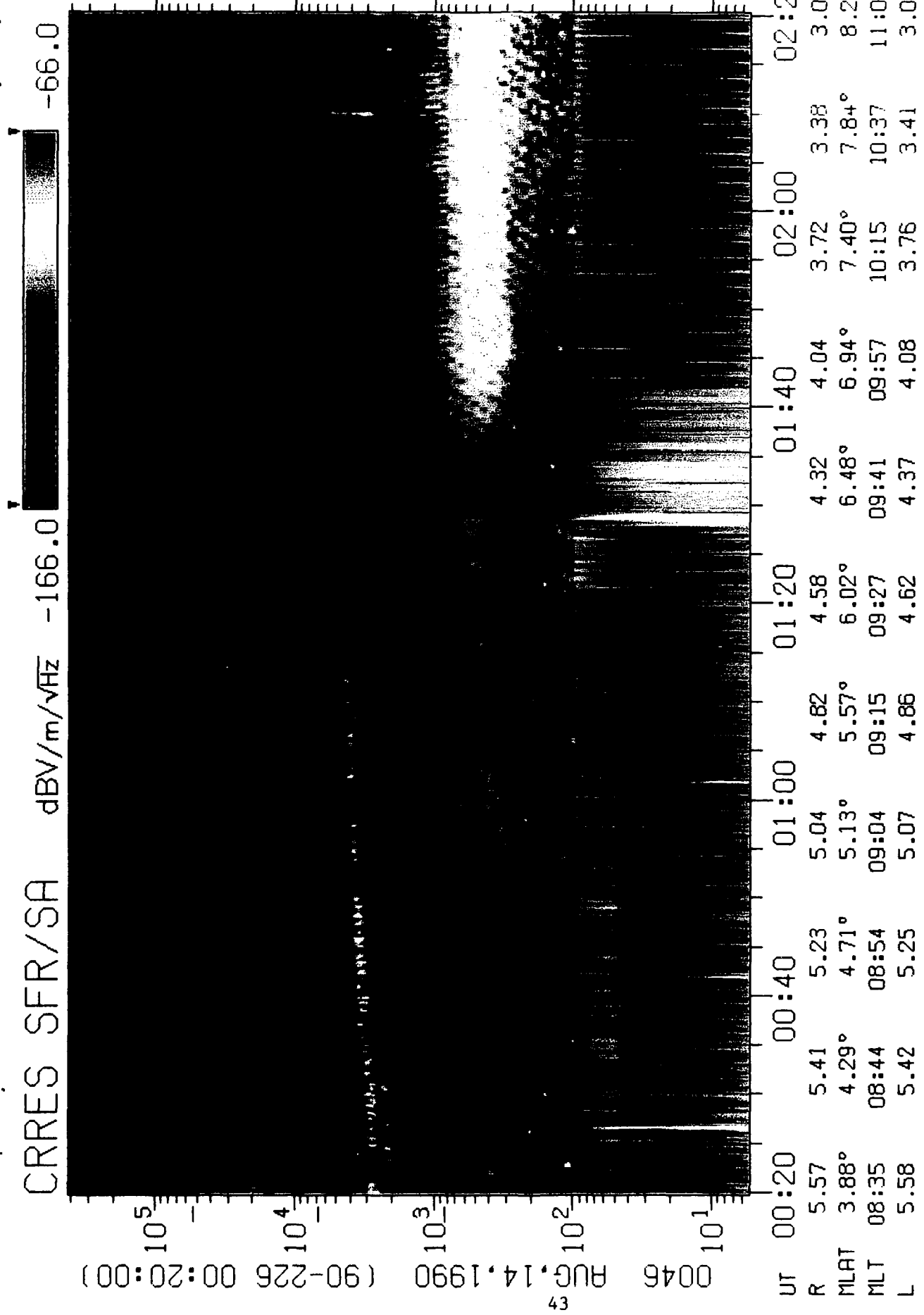


Figure 10

plasmasphere. The most intense part of AKR is usually around 250 kHz. However, the higher the frequency the AKR is, the lower is the altitude at which it is generated and the more likely that it will be shielded by the plasmasphere. The detection of AKR by CRRES is an indication of increased geomagnetic activity but is somewhat limited by the above constraints. A future event study will address determining certain aspects of the structure of the plasmasphere by using the remotely generated AKR as a sounder.

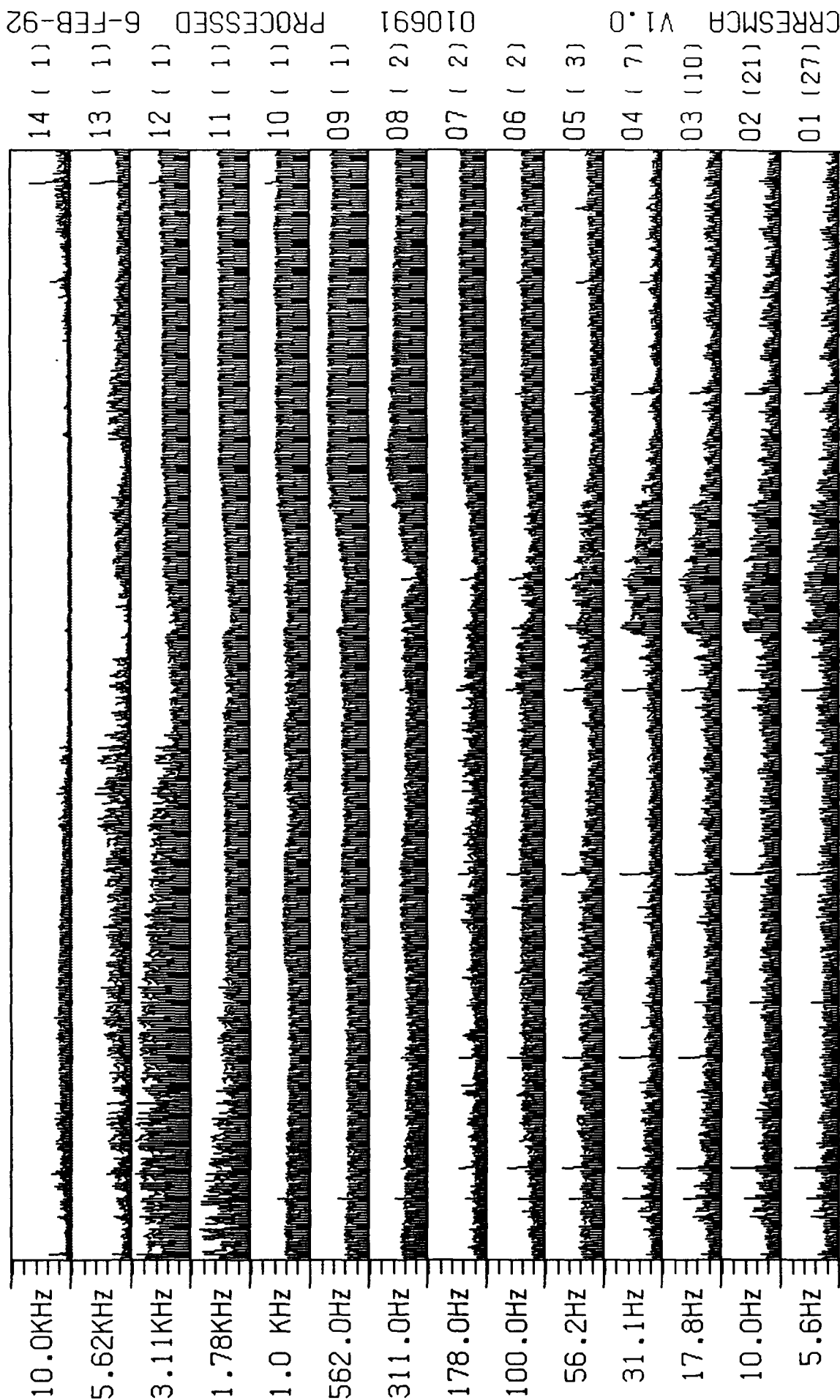
Figures 11 and 12 are plots of the 5.6 Hz to 10 kHz Spectrum Analyzer data for the same time period as shown in Figure 10, for the electric and magnetic sensors, respectively. The isolated narrow peaks occurring simultaneously in several channels are interference glitches due to bias sweeps done by the Langmuir Probe Experiment. The electrostatic nature of the very low frequency emissions from 01:28 UT to 01:42 UT is clearly evident. These very low frequency electrostatic emissions are observed both near the plasmopause and during periods of enhanced fluctuations in the plasma density. A study is underway attempting to determine the source of these emissions.

Interesting features evident in the magnetic data include the narrow abrupt enhancement in the plasmaspheric hiss right at the final plasmopause crossing at 01:42 UT and the degree to which the intensity and bandwidth of the hiss increase at and following this crossing. Studies are underway to determine whether the changes in the hiss characteristics are due to propagation effects or due to local wave-particle generation or amplification processes.

All of the previous color spectrograms have contained about two hours worth of data and show the SFR data in their highest possible

CRRES MCA AUG, 14, 1990 (90-226) 00:20:00

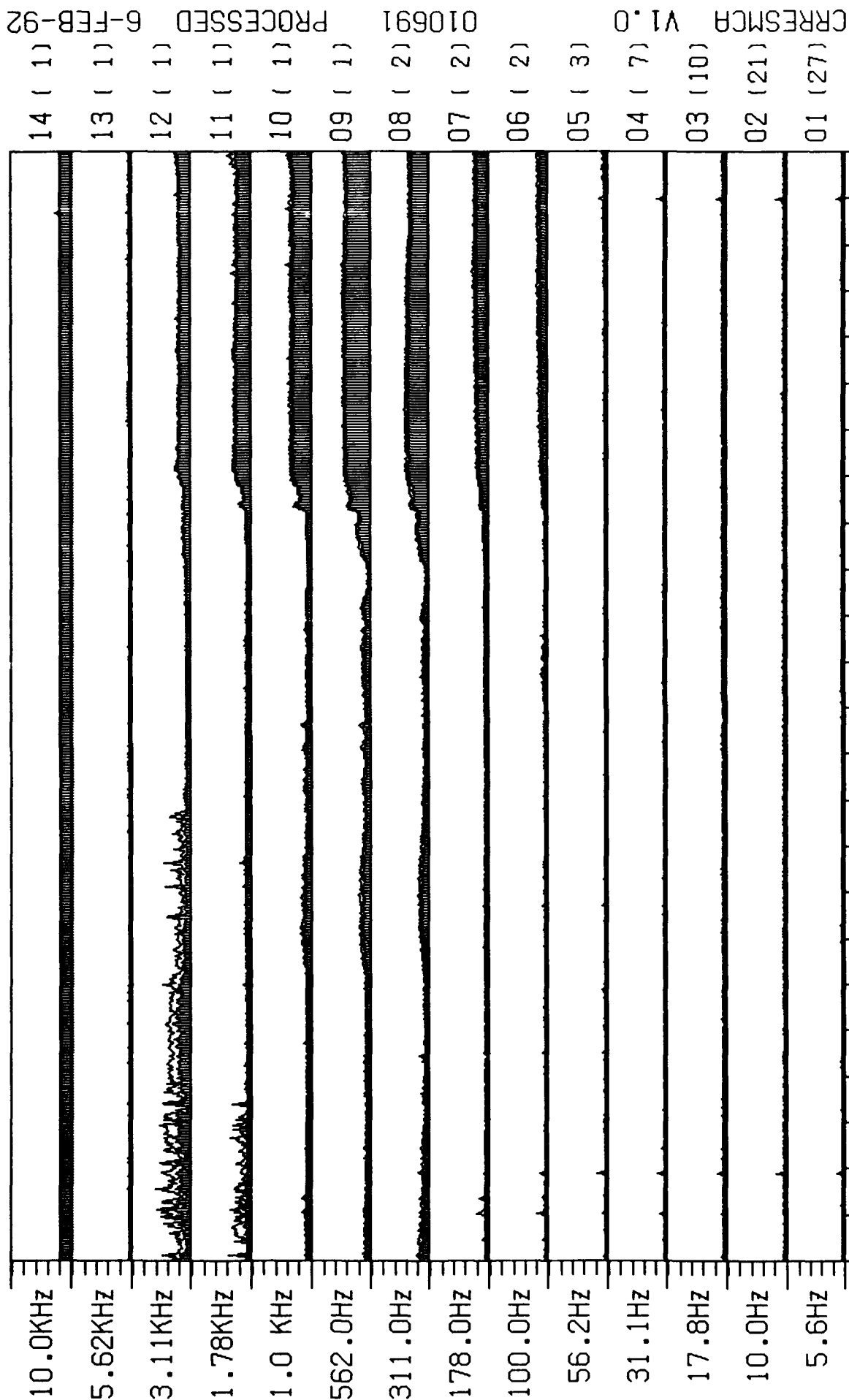
ORBIT 00046 ELEC ANTENNA 2 HR



00:20:00 00:40:00 01:00:00 01:20:00 01:40:00 02:00:00 02:20:00

CRRES MCA AUG,14,1990 (90-226) 00:20:00

ORBIT 00046 MAG ANTENNA 2 HR



time resolution. In order to view a complete orbit of data, we developed programs to display ten hours worth of data. Figure 13 shows the color spectrogram for Orbit 90 which began at 19:18 UT on August 31, 1990 (day 90-243). The large variation in number density and plasma wave modes throughout an orbit is quite evident. The ECH waves are seen to be more intense the lower the plasma density is. The strong enhancements in the ECH waves and a low frequency set of emissions near the magnetic equator are also evident.

Figures 14 and 15 are plots of the 5.6 Hz to 10 kHz Spectrum Analyzer data for the same time period as shown in Figure 13, for the electric and magnetic sensors, respectively. The isolated narrow peaks occurring simultaneously in several channels of the electric plot are interference glitches due to bias sweeps done by the Langmuir Probe Experiment. The electrostatic nature of the ECH emissions and the low frequency emissions near and below 100 Hz around the magnetic equator crossing around 22:50 UT is clearly evident from a comparison of the electric and magnetic plots. The various hiss and chorus bands observed are clearly electromagnetic as their signals exist in both the electric and magnetic data.

In order to analyze the data from the March 1991 storm period, we have now produced 10-hour color spectrograms and Spectrum Analyzer plots from one week before the storm to one month after the storm.

3.3 Initial Results and New Discoveries

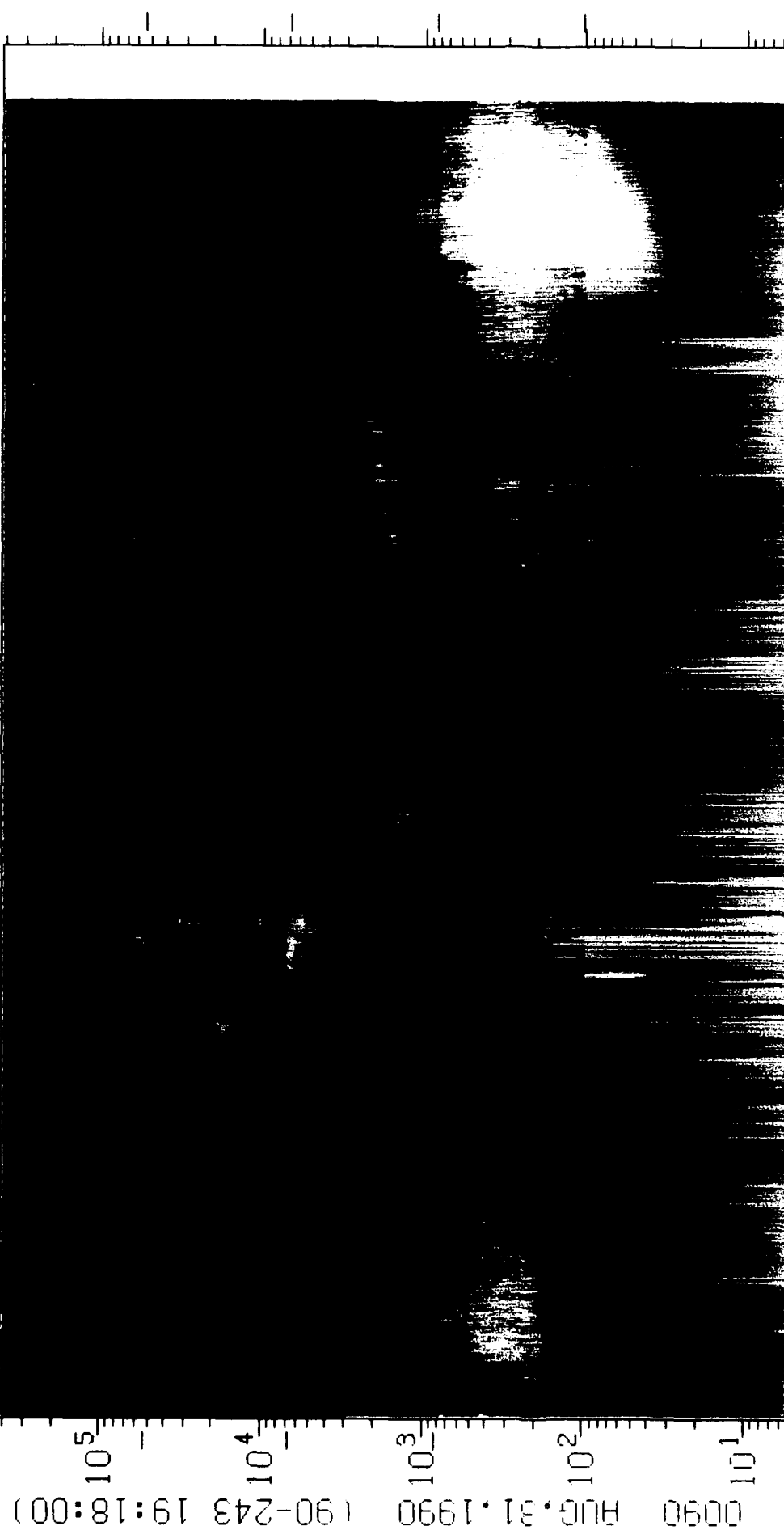
From the examples we have shown above in Sections 3.1 and 3.2, it is clear that the CRRES Plasma Wave Experiment is producing valuable data for determining the plasma density along the CRRES orbit, for studying the plasma wave environment in the radiation belts, for

CRRES SFR/SA

dBV/m/√Hz

-166.0

-66.0

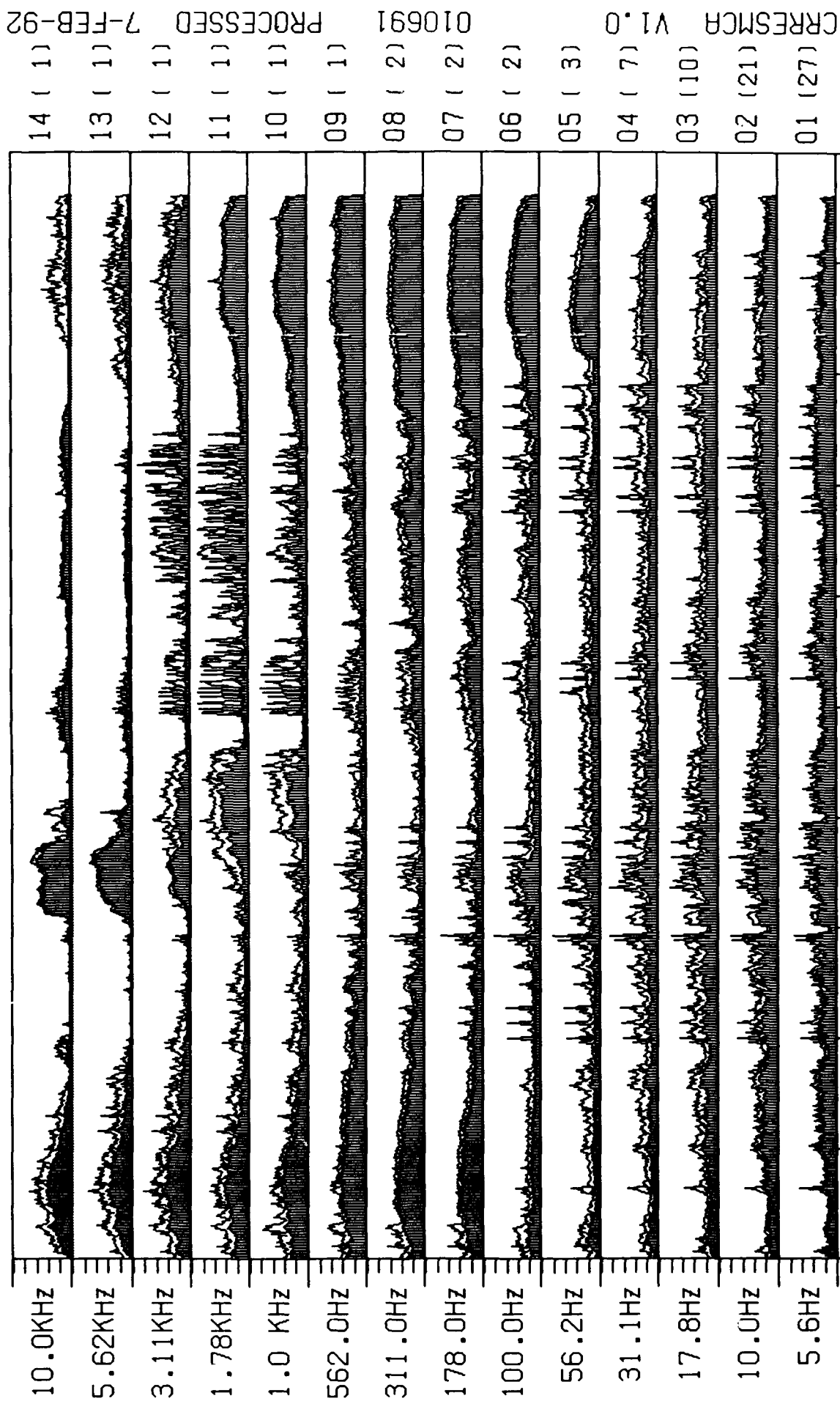


UT	19:18	21:18	23:18	01:18	03:18	05:18
R	1.07	2.97	5.55	6.07	5.49	2.82
MLAT	-4.02°	-13.41°	-2.00°	5.11°	6.97°	6.81°
MLT	17:56	03:01	05:27	07:17	07:58	10:44
L	1.20	3.09	5.63	6.17	5.62	2.83

Figure 13

CRRES MCA AUG.31,1990 (90-243) 19:18:00

ORBIT 00090 ELEC ANTENNA 10 HR



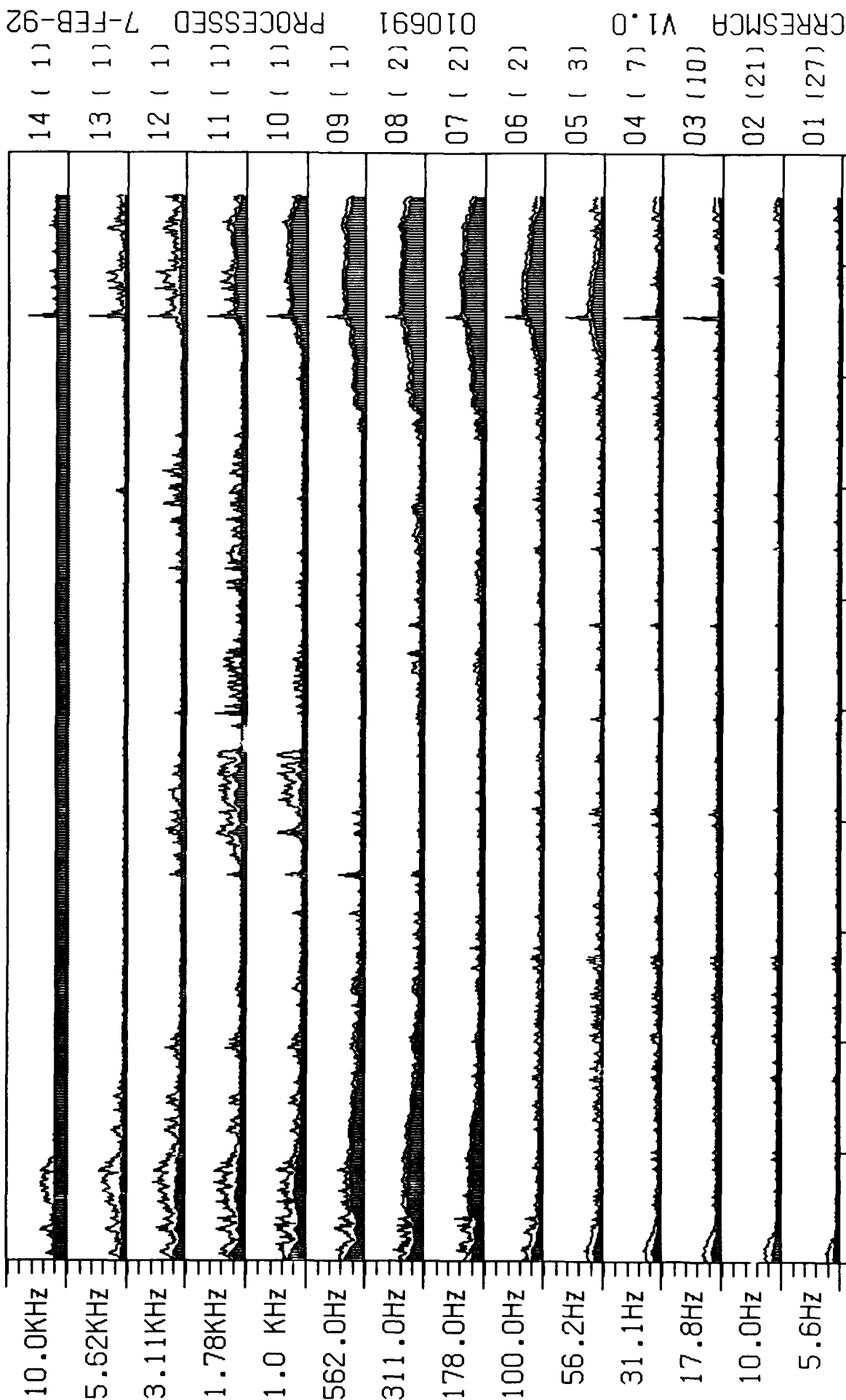
CRRESMCA V1.0
PROCESSED 7-FEB-92
010691

Figure 14

01800CRO

CRRES MCA AUG,31,1990 (90-243) 19:18:00

ORBIT 00090 MAG ANTENNA 10 HR



19:18:00 21:18:00 23:18:00 01:18:00 03:18:00 05:18:00

01800CA0

Figure 15

studying wave-particle interactions, and for understanding the dynamics of the plasma and particles in the magnetosphere out to geosynchronous orbit.

Within the plasmasphere outside of about $2 R_E$ when the plasma density is below $2 \times 10^3 \text{ cm}^{-3}$, emissions at the Upper Hybrid Resonance frequency are clearly detected by the PWE and are providing excellent data from which the plasma density profiles are being extracted. Outside of the plasmasphere the plasma frequency cutoff of the continuum radiation is being used to extract the number density profiles. Analyses of the plasma density data have revealed even more fine structure than was previously observed. The rapid eight-second sweep rate on the SFR has allowed us to detect very rapid density fluctuations within the plasmasphere, at the plasmopause, and in the trough region. These observations show that density structures with scale lengths of a few tens of kms exist in the magnetosphere.

Another new discovery in the plasma density data is the existence of deep depletions in number density of the order of factors of four to sixteen well inside the plasmasphere (usually around $L = 3$) with a typical width of about one half an R_E and which are observed for several orbits.

Analyses of the plasma density data also show a large variety in the density profiles near the plasmopause. The relatively short 10-hour orbital period for CRRES allows us to observe the relative changes in the plasmopause location and structure several times per day. This is especially useful for studying the plasma dynamics and plasmasphere refilling processes following geomagnetic storms and substorms.

The CRRES PWE data have also shown numerous plasma wave phenomena to be associated with the plasmopause. Usually the plasmaspheric hiss is predominantly inside the plasmopause and chorus is outside the plasmopause. The CRRES observations show that occasionally some of the chorus can be found inside the plasmasphere and some of the plasmaspheric hiss can be found outside.

Strong low frequency electromagnetic whistler-mode hiss emissions well below the frequency of co-existing whistler-mode chorus emissions have been observed on many occasions just outside the plasmopause. On past experiments these emissions were hidden in the interference noise generated by the rapidly rotating solar arrays going into and coming out of the sunlight.

A strong very low frequency electrostatic emission is frequently detected at the plasmopause where the steep density gradient occurs. Moderately intense very low frequency electrostatic emissions are observed when the number density fluctuates. The stronger the number density fluctuation, the more intense the electrostatic emissions. Both of these types of electrostatic emissions were hidden in the past by the interference from solar arrays.

Numerous hiss bands are frequently observed inside the plasmasphere which indicates that multiple populations of particle energies are producing them. The hiss bands are observed to have a low-frequency cutoff at the proton cyclotron frequency and frequently intensity enhancements above the lower hybrid resonance (LHR) frequency. The observation of the lower frequency cutoff had been masked in the past by the solar array interference. Another new result obtained using the CRRES data is that the enhancement in intensity

above the LHR frequency is stronger and more noticeable in the higher latitude perigee passes.

Numerous chorus and hiss bands are frequently observed outside the plasmasphere which also indicates that multiple populations of particle energies are producing them. The hiss bands detected outside the plasmasphere tend to have little variation in frequency while the chorus bands tend to occur at a constant fraction of the electron cyclotron frequency. However, sometimes the chorus bands change frequency in a manner apparently unrelated to the cyclotron frequency which indicates a rapidly changing population of particles associated with them.

The dominant emissions of terrestrial origin above the plasma frequency in the CRRES data make up the "continuum" radiation. CRRES observations clearly support past studies showing the plasmopause as a source of much of this radiation. The CRRES observations of the presence of enhanced levels of continuum radiation in many of the isolated regions of high plasma density (and believed at one time to be detached plasma regions) strongly suggest that these certain isolated regions are still connected to the plasmasphere at some point.

The CRRES data show that ECH emissions are nearly always present outside the plasmasphere but that they vary tremendously in intensity. CRRES studies confirm that the most intense emissions are generated near the magnetic equator. New results from CRRES show that the intense emissions usually occur in the upper part of the gyroharmonic ratio. The relative frequency location in the gyroharmonic band of all ECH emissions was found to be sensitive to the F_{UHR}/F_{ce} ratio. Another

new finding from CRRES is that a low frequency emission frequently is observed simultaneously with the intense ECH emissions.

When CRRES is inside the plasmasphere at the geomagnetic equator, the UHR emission line is observed to be enhanced and to be a source for components of the escaping continuum radiation.

Analyses of data from geomagnetic storm periods show that the intensities of various plasma wave emissions over very broad frequency intervals are elevated for up to several days. A fascinating but as yet unexplained new discovery is that the CRRES PWE detected a low frequency electromagnetic pulse coincident with the storm sudden commencement for the March 1991 storm.

Several factors have made the CRRES PWE data especially useful for measuring the plasma wave environment in the radiation belts, for studying the dynamics of the plasma and particles in the earth's magnetosphere, and for studying wave-particle interactions. The most important ones are discussed below.

The low frequency noise level on CRRES was very low. At very low frequencies (below 100 Hz), very low noise levels have been observed in the CRRES Plasma Wave Experiment data as compared to previous satellite experiments that have flown in the same region. The primary reason for this very pleasant result is that the entire CRRES solar array is continuously illuminated and that the solar array strings are not rotating into and out of sunlight. This allows the study of plasma wave phenomena at lower frequencies than possible with earlier spacecraft.

The higher time resolution on the Sweep Frequency Receiver has enabled the identification of more significant fluctuations in various

plasma wave phenomena than had been identified earlier. Especially impressive is the degree to which the electron number density fluctuates over very short temporal and spatial scales.

The short (less than 10 hour) orbital period of CRRES has allowed us to identify phenomena such as deep depressions in number density deep in the plasmasphere that last for several orbits and to observe rapidly changing features such as the plasmopause location during geomagnetic substorms and storms.

The slow spin rate of CRRES has allowed the observation of plasma modes that are difficult to discern and study on spacecraft spinning faster.

The somewhat shorter antennas on CRRES (100 meters as opposed to 215 meters) as compared to ISEE plus nearly a full 100 dB of dynamic range (the ISEE SFR dynamic range was between 80 and 90 dB dependent on the band) resulted in much less saturation of the CRRES data.

4. FUTURE PLANS

The highest priority item will be the extraction of the electron number density from the remaining orbits and the transferring of copies of this newly extracted data to AFGL. Using these extracted data along with that already completed, we will construct model profiles for various local times and geomagnetic conditions. If time and resources permit, we will attempt to use neural networks in programming to extract the electron number density and compare the results with our manually extracted data.

The numerous event studies described above as in progress will be completed. The statistical studies underway will be continued by first adding data from the remainder of the CRRES lifetime and then completing the studies. Because of their usefulness in giving an excellent overview of the plasma wave phenomena for an entire orbit and for comparing consecutive orbits, we will produce 10-hour color spectrograms for all of the CRRES orbits. These spectrograms will be used to identify new event studies.

For the event studies we are continuing as well as the new ones we choose to work on, much emphasis will be placed on examining the plasma and particle data in order to identify the sources for emissions such as the Electron Cyclotron Harmonic waves, chorus and banded chorus, ELF hiss, banded hiss, and plasmaspheric hiss. We are especially interested in identifying the various particle populations associated with the different bands and the different plasma wave phenomena. We will also concentrate on understanding the electrostatic emissions near the plasmopause and as well as those associated with strong plasma density fluctuations. For all of these studies we will examine data

both from geomagnetic storm and substorm periods and from quiet time periods.

New statistical studies contemplated include determining the average electric and magnetic field strengths for various frequency intervals as a function of radial distance, local time, and magnetic latitude for different geomagnetic conditions. Fixed frequency intervals as well as intervals based on the extracted plasma frequency and electron cyclotron frequency will be used. Results from these studies will be used to compare with the plasma and particle data from other CRRES instruments in order to better understand the wave-particle interactions taking place.

5.0 CONTRACT AND PERSONNEL ACKNOWLEDGMENTS

The primary contract at The University of Iowa for the operation and monitoring of the CRRES Plasma Wave Experiment in orbit and for the SPACERAD data reduction, data analysis, and modeling efforts is Air Force Geophysics Laboratory (AFGL) Contract No. F19628-90-K-0031.

The primary hardware contract under which the CRRES Plasma Wave Experiment was designed, constructed, tested, calibrated, and initially integrated was AFGL Contract No. F19628-82-K-0028.

The subcontract which provided for continuing and additional testing and calibrations and the reintegration, pre-launch testing, and initial flight operations was Assurance Technology Corporation subcontract 2376-13.

The subcontract for the NASA support for The University of Iowa participation in the CRRES Chemical Release Investigator Working Group activities and in the CRRES Chemical Release planning, operations, and data analysis activities is Subcontract Number 9-X29-D9711-1 with the University of California, Los Alamos National Laboratory.

Dr. Roger R. Anderson, a Research Scientist at The University of Iowa, is the Principal Investigator for The University of Iowa Contracts and Subcontracts listed above. He is a Co-Investigator for the CRRES SPACERAD AFGL 701-13-2 and AFGL 701-15 experiments (E. G. Mullen, GL/PHP, is the Principal Investigator for SPACERAD (AFGL 701)). He directs the CRRES Plasma Wave Experiment investigation and is involved in all of the scientific analyses.

Professor Donald A. Gurnett is a Co-Investigator for The University of Iowa Contracts and Subcontracts listed above. He is the

graduate adviser for the graduate students working on the CRRES data and participates in the scientific analyses of the CRRES data.

Michael LeDocq is a graduate student working on the analysis of the quasi-periodic fluctuations in the CRRES electron number density data.

Allen Kistler is a graduate student studying "continuum radiation storms" in the CRRES plasma wave data.

Janet McLarty is an undergraduate Honors student who is studying the variation in plasmopause locations as determined from an analysis of the CRRES electron number density data.

APPENDIX 1: ABSTRACTS OF PAPERS AND PUBLICATIONS

This appendix contains the abstracts of the papers and publications relevant to the CRRES Plasma Wave Experiment which have been produced under this data reduction and analysis contract and under the previous hardware contracts.

The following paper is the CRRES Hardware Contract Final Report:

CRRES SPACERAD Plasma Wave Experiment
R. R. Anderson and D. A. Gurnett
Final Report, Air Force Geophys. Lab., AFGL-TR-88-0299, 1988, ADA 210791

This document is the Final Report for Contract F19628-82-K-0028 from the Air Force Geophysics Laboratory under which the University of Iowa Department of Physics and Astronomy designed, constructed, tested, and delivered a Main Electronics Package (AFGL 701-15A), two Electric Field Preamps (AFGL 701-15B and AFGL 701-15C) and Search Coil Magnetometer (AFGL 701-13-2) (collectively known now as either the Passive Plasma Sounder (PPS) or the Plasma Wave Experiment) as a part of the AFGL 701 SPACERAD instrumentation on the CRRES (Combined Release and Radiation Effects Satellite) project. The report is divided into nine sections. Section 1 contains the introduction. Section 2 discusses the scientific objectives and the importance of the Plasma Wave Experiment in the CRRES SPACERAD mission. Section 3 describes the instrument design rational and the instrument development philosophy. The instrument description is contained in Section 4. Section 5 describes the instrument commands and their verifications. Section 6 discusses the testing and operations of the experiment. Section 7 contains a schematic drawing of the instrumentation electronics and lists of the schematics, drawings, and wiring diagrams that describe the as-built configuration of the Plasma Wave Experiment instrumentation. Problems encountered during the construction and testing of the instrument and their resolutions are discussed in Section 8. Conclusions and recommendations are included in Section 9. Test results from already completed environmental and EMC/RFI tests have already been submitted to AFGL and to the Air Force Headquarters Space Division Space Test Program. The recertification of the calibration of the instrument is recommended in the near future under a new contract covering the re-delivery (necessitated due to the removal during the launch-delay storage period), pre-launch, and launch operations.

The following paper has been accepted for publication in the Journal of Spacecraft and Rockets. A copy of the entire paper is included in Appendix 2.

The CRRES Plasma Wave Experiment

R. R. Anderson, D. A. Gurnett, and D. L. Odem

Accepted for publication, J. Spacecraft and Rockets, 1992.

Abstract. The CRRES Plasma Wave Experiment is designed to provide information on the plasma wave environment and the total plasma density in the Earth's radiation belts and throughout the CRRES orbit. This information is valuable both for studying the naturally occurring wave-particle interactions affecting the plasma and particle environment in the plasmasphere and magnetosphere as well as for studying the chemical releases. The electric field sensors for this instrument consist of two long electric dipole antennas (~100 m tip-to-tip) and the magnetic field sensor is a search coil magnetometer mounted at the end of a 6-meter boom. The instrument has two receivers: a 14-channel spectrum analyzer covering the frequency range from 5.6 Hz to 10 kHz and a 128-step sweep frequency receiver covering the frequency range from 100 Hz to 400 kHz. Measurements from these receivers provide the intensity of the electromagnetic and electrostatic fields as functions of frequency and time from which the emissions and wave modes can be identified and analyzed and from which the total plasma number density can be determined.

The following paper has been submitted to the Journal of Geophysical Research:

Banded Electrostatic Emissions Observed by the CRRES Plasma Wave Experiment

C. Paranicas, W. J. Hughes, H. J. Singer, and R. R. Anderson

Submitted for publication, J. Geophys. Res., 1991.

A survey of banded electrostatic emissions observed by the Plasma Wave Experiment on the recently launched spacecraft "CRRES" is presented with an emphasis on the relation of the frequency of the highest intensity waves to harmonics of the local electron cyclotron frequency. Because one of its goals is a first look at the CRRES high-frequency electric field data, all the data discussed in this paper was taken in the first 8 months after launch. During this time emissions are detected chiefly in the post-midnight quadrant of the magnetosphere between $L=3.5$ and $L=7$. We confirm that high intensity emissions are confined to within a few degrees of the magnetic equator. These emissions generally favor the upper part of the gyroharmonic interval and their frequency is sensitive to the ratio of the upper hybrid resonance frequency to the electron cyclotron frequency. The f_{uhr}/f_{ce} ratio is also important for the lower-intensity emissions detected off the magnetic equator.

The following paper was presented at the AIAA, 28th Aerospace Sciences Meeting in Reno, NV, in January 1990:

CRRES FIELDS AND WAVES MEASUREMENTS

R. R. Anderson

American Institute Aeronautics and Astronautics, 28th Aerospace Sciences Meeting, #AIAA-90-0524, 1990.

The three major objectives of the Combined Release and Radiation Effects Satellite (CRRES) mission are (1) studies of the natural radiation environment and studies of the effects of this radiation environment upon microelectronic components as CRRES travels through the inner and outer radiation belts of the earth, (2) performance of active chemical release experiments in the ionosphere and magnetosphere, and (3) low altitude studies of ionospheric irregularities. In-situ measurements of the fields and waves in the vicinity of the CRRES spacecraft are essential in order to meet the objectives of the CRRES mission. Five instrument groups on CRRES have been designed, constructed, integrated, and tested to perform the fields and wave measurements. Three of the fields and waves instruments are a part of the AFGL 701 SPACERAD (Space Radiation Experiment) complex: the Fluxgate Magnetometer (AFGL 701-13-1), the Langmuir Probe - Cold Plasma Experiment (AFGL 701-14), and the Plasma Wave Experiment which consists of the Search Coil Magnetometer (AFGL 701-13-2) and Passive Plasma Sounder (AFGL 701-15). The other two fields and wave instruments are a part of the NRL 701 LASSII (Low Altitude Satellite Studies of Ionospheric Irregularities) complex: The Pulsed Plasma Probe and the Very Low Frequency Wave Analyzer. The CRRES fields and waves experiments' instrumentation, scientific objectives, measurements that will be performed to meet these objectives, and expected results will be described in this paper.

The following paper was presented at Plasmasphere Refilling Workshop in Huntsville, AL, in October 1990:

Dynamical Plasma Parameters and Processes Deduced from Plasmaspheric Plasma Wave Observations
Roger R. Anderson

In situ ULF up to MF plasma wave observations over the past two decades have provided useful diagnostics for determining parameters in the plasmasphere and outer magnetosphere such as density, relative temperatures, and boundary locations. Within the plasmasphere the total plasma number density can be determined from the enhanced emissions at the upper hybrid resonance frequency. In the outer magnetosphere the lower cutoff of electromagnetic radiation at the plasma frequency provides a direct measurement of the electron number density. These techniques provide the total number density independent of spacecraft charging and without perturbing the plasma. The plasmopause can be identified by the steep drop in number density as deduced from emissions

at the upper hybrid resonance frequency as the spacecraft moves outward. Frequently this boundary can also be identified by the termination of the plasmaspheric hiss and the onset of electromagnetic chorus and electrostatic electron cyclotron harmonics. Observed changes in the densities within the plasmasphere and in the location and structure of the plasmopause provide much information on the loss and refilling processes taking place. ISEE plasma wave observations have provided both statistical and case studies over nearly a ten-year period on how the densities change as a function of geomagnetic activity. We now are getting exciting new measurements from CRRES which with its higher time-resolution sweep frequency receiver is able to show even more structure in the densities measured in the plasmasphere and at the plasmopause. CRRES is in a geosynchronous transfer orbit at an 18 degree inclination with a 10-hour period that provides timely monitoring on the state of the equatorial plasmasphere and magnetosphere from $L=1.1$ to $L=7.3$ as a function of geomagnetic activity. Both the past results from ISEE and the new results from CRRES will be examined.

The following paper was presented at the Fall AGU Meeting in San Francisco, CA, in December 1990:

Initial Results from the CRRES Plasma Wave Experiment
R. R. Anderson, D. A. Gurnett, D. L. Odem, H. J. Singer

The University of Iowa/AFGL Plasma Wave Experiment on the Combined Release and Radiation Effects Satellite (CRRES) has a 128-channel (r bands each having 32 channels) Sweep Frequency Receiver (SFR) covering the frequency range from 100 Hz to 400 kHz and a 14-channel Spectrum Analyzer (SA) covering the frequency range from 5.6 Hz to 10 kHz. Logarithmic compressors for each of the four SFR bands and for each of the 14 SA channels provide amplitude measurements with a dynamic range of about 100 dB. The SA provides high time resolution (8 spectra per second) with coarse frequency resolution while the SFR provides high frequency resolution with coarse time resolution (1 spectra in 32 seconds for the lowest frequency band (100 Hz to 800 Hz), in 16 seconds for the next higher band (800 Hz to 6.4 kHz), and in 8 seconds for the two highest frequency bands (6.4 kHz to 50 kHz and 50 kHz to 400 kHz). Three sensors are available by command for each of the receivers: a 100-m tip-to-tip long wire electric dipole antenna, a spherical double probe antenna with a sphere-to-sphere separation of 96 meters, and a search coil magnetometer. CRRES was launched on July 25, 1990, into an equatorial geosynchronous transfer orbit with an 18 degree inclination, 350 km perigee altitude, 33500 km apogee altitude, and an orbital period of 9.85 hours. CRRES thus provides timely monitoring on the state of the equatorial plasmasphere and magnetosphere from $L=1.1$ to $L=7.3$ as a function of time, spatial location, and geomagnetic activity. The magnetometer boom was deployed and the antennas extended during the first week of operations. The Plasma Wave Experiment is operating perfectly and has yielded a wealth of significant observations. Within the plasmasphere the total plasma number density can be determined from the observed enhanced emissions at the upper hybrid resonance frequency. In the outer magnetosphere the lower cutoff of electromagnetic radiation

at the plasma frequency provides a direct measurement of the electron number density. These techniques provide the total number density independent of spacecraft charging and without perturbing the plasma. We now are getting exciting new measurements from CRRES which with its higher time-resolution sweep frequency receiver is able to show even more structure in the densities measured in the plasmasphere and at the plasmopause than had been observed previously. The plasmopause can be identified by the steep drop in number density as deduced from emissions at the upper hybrid resonance frequency as the spacecraft moves outward. Frequently this boundary can also be identified by the termination of the plasmaspheric hiss and the onset of electromagnetic chorus and electrostatic electron cyclotron harmonics. Other plasma wave phenomena observed by CRRES include whistlers, ELF hiss, lower hybrid resonance emissions, Auroral Kilometric Radiation, and type III solar radio bursts.

The following papers were presented at the Spring AGU Meeting in Baltimore, MD, in May 1991:

CRRES Plasma Wave Observations at the Plasmopause
R. R. Anderson

CRRES plasma wave observations show that a variety of changes in the type and intensity of plasma waves detected frequently occurs at or near the plasmopause. For plasmapauses with steep density gradients, plasmaspheric hiss is usually found only inside the plasmopause and chorus and electron cyclotron harmonic waves are usually found only outside the plasmopause. For more gradual density gradients the plasmaspheric hiss can be found to extend some distance outside the plasmopause. On some occasions hiss bands within the plasmasphere merge into chorus bands outside the plasmopause. However, some low frequency hiss bands occasionally continue from inside the plasmopause to outside the plasmopause without any significant change in structure or intensity. On numerous occasions, an intense very low frequency emission (usually below 100 Hz) has been detected just outside the plasmopause. When the plasmopause is highly structured, many of the wave emissions show evidence for ducting. Changes in the plasma, particle, and field parameters that may be associated with the changes in the waves will be examined.

Diamagnetic Cavities Formed by the CRRES High Altitude Chemical Release Experiments

H. J. Singer, W. J. Hughes, R. Anderson, J. Wygant, W. McNeil, D. L. Reasoner

During January and February 1991, the Combined Release and Radiation Effects Spacecraft (CRRES) released canisters of barium and lithium at high altitudes in the nightside magnetosphere. Along with other diverse objectives of these experiments, the opportunity was provided to examine the diamagnetic cavities formed by each of the releases. There have been very few chemical releases with in situ

observations at high altitude and the CRRES releases greatly expand the observational data base that can be used to understand the physics of the environmental interactions under these conditions. In contrast to the AMPTE experiments where all of the releases were in background fields weaker than 40 nT, the eight separate CRRES releases occurred in background magnetic fields ranging from 5000 nT to about 93 nT. Preliminary results show that the release at 5000 nT caused the field to decrease by about 30 nT. The other releases produced cavities with the primary cavity duration ranging from a few seconds to about 50 seconds. The background magnetic field was totally excluded only in the two large barium releases in 135 nT and 93 nT background fields. The barium cavities lifetimes can be ordered by examining the balance between magnetic and thermal plasma pressure. In these first results, we will present data regarding the cavity lifetimes, strengths, associated magnetic field variations and the relation to plasma wave and electric field observations.

Observations of Whistler Wave Packets Embedded in 10-100 Millisecond Density Depletions from the UCB/AFGL Langmuir Probe/Electric Field Experiment on CRRES

J. R. Wygant, R. E. Ergun, F. S. Mozer, I. Roth, N. Maynard, H. Singer, M. Smiddy, R. Anderson

This paper presents observations from the UC Berkeley/AFGL Langmuir Probe/Electric Field Experiment on the CRRES satellite, near L=5 to 6, of discrete whistler wave packets which coincide with density depletions ($\delta n/n \sim .2$). The measurements of the electric field, magnetic field (from the University of Iowa/AFGL search coil) and plasma thermal current are provided by the LP/EFE burst memory at individual sampling rates of 2000 samples/sec. The whistler waves have a frequency of 300 Hz and are organized into discrete wave packets lasting 10-100 milliseconds. The magnitude of the wave electric field is 1 mV/m, while the wave magnetic field is about 0.1 nT with $\delta B/B \sim 10^{-3}$ and a phase velocity of about 10,000 km/sec. Depletions in plasma thermal currents coinciding with each wave packet are interpreted as density drop outs. These observations are discussed in terms of a possible modulational instability or alternatively as the result of whistler wave emission from electrons trapped in a low frequency wave.

Real Time Monitoring of the Geophysical Parameters in Support of the CRRES Chemical Releases

S. B. Mende, H. L. Collin, W. K. Peterson, G. Haerendel, R. R. Anderson, D. A. Hardy, H. J. Singer, J. C. Foster, D. L. Reasoner

The high altitude releases of the CRRES program were active experiments whose success depended strongly on the ambient magnetospheric geophysical conditions. During the January and February campaign the magnetospheric conditions were monitored in real time prior to release in an attempt to predict conditions for each release. The small barium releases were designed to test the interaction of the ion clouds with the ambient magnetospheric environment during conditions of widely varying ambient cold plasma densities. For these releases the in

situ cold plasma density was monitored through the real time observation of the wave receiver on the CRRES satellite. The large barium clouds were intended to produce auroral enhancements at the foot of the magnetic field line. In addition to the knowledge of the cold plasma density at the satellite these experiments required the observation of the auroras at the foot of the field line, measurements of the ionospheric electric fields in the conjugate ionosphere and reading of the magnetic field and energetic particle data at the satellite. The auroral conditions were observed by the instrumented aircrafts and the ionospheric fields were measured by the Millstone Hill incoherent scatter radar. During these releases the required geophysical conditions were met which contributed to the success of the experiments. The large Li releases were intended to precipitate local fluxes of energetic electrons by pitch angle diffusion in the presence of the artificially injected cold lithium ions. This experiment dictated the toughest conditions because it required low cold plasma density, high electron fluxes at the satellite and uniform dim auroras at the conjugate region. During the campaigns excellent sets of data were gathered which characterized the aurora, the simultaneous particle and field measurement at the satellite and the accompanying convection in the ionosphere during various conditions.

Magnetospheric Response to the 26 August 1990 Sudden Commencement
M. D. Violet, M. S. Gussenhoven, H. J. Singer, D. H. Brautigam, D. A. Hardy, K. J. Kerns, R.R. Anderson, C. E. Jordan, J. N. Bass, G. R. Ludlow, A. Vampola, A. Korth

A shocked solar wind led to a sudden commencement (SC) at 0543 UT on 26 August 1990. Prior to the SC the IMF was in an away sector with B_z near zero. For 30 minutes after the SC, all three components of the IMF were positive, with $B = 15$ nT. After this all components turned negative with B increasing to 20 nT. A moderately large magnetic storm ensued. Instruments on the CRRES satellite at 6.2 RE, 12° MLAT, and 6:35 MLT, measured the magnetospheric response to the SC. The immediate magnetic field change at CRRES was a sharp increase of 15 nT in magnitude and the onset of wave trains primarily in the east-west direction. The SC was preceded by several Type 3 radio bursts and followed by a dramatic increase in chorus. The intensities and pitch angle distributions of ions and electrons from 10s of eV to several MeV exhibited a variety of large-scale, quasi-stationary and small, oscillatory changes. The proton population extended to higher than normal energies because a solar proton event was in progress. We model these changes using the Hilmer-Voigt magnetic field model and low altitude precipitating electron and ion fluxes measured on the DMSP satellites.

Inner Magnetosphere Morphology During the 26 August 1990 Geomagnetic Storm

K. J. Kerns, M. S. Gussenhoven, D. A. Hardy, D. H. Brautigam, H. J. Singer, R. R. Anderson, E. G. Holeman, D. Madden, C. E. Jordan

A comparison of auroral energy plasma sheet ions and electrons at high and low altitudes is made for the initial phase of the 26 August, 1990 magnetic storm. The high altitude measurements are made on the CRRES satellite in geosynchronous transfer orbit. The low altitude measurements are made on the DMSP satellites in circular, polar orbits. We use a variety of magnetic field models (Olson-Pfitzer, Tsygenenko, Hilmer-Voigt, Stern) to trace magnetic field lines between the two locations. At the time of the sudden storm commencement, 0543 UT, CRRES was near the magnetic equator on the dawn side of the magnetosphere at an L of 6.2. CRRES was positioned Earthward of the plasma sheet boundary, but outside of the plasmasphere, that is, in the plasma trough. The low altitude dawn equatorward auroral boundary was 66° MLAT and the oval was very quiet. By 0800 UT, after the IMF Bz component had been southward for more than 1.5 hr. the low altitude morning auroral boundary at 06 MLT had expanded to 58° MLAT. The expansion was not uniform in magnetic local time, and at 09 MLT the boundary remained contracted. Also at 0800 MLT CRRES entered the plasma sheet. It was positioned at 08 MLT and at L=6.4. CRRES exited the plasma sheet at 09:30 UT positioned at 09:30 MLT and an L of 5. By this time the low altitude boundary in the same local time sector had also expanded to 58° MLAT. We use the time that CRRES traversed the plasma sheet to identify corresponding populations at low altitude and to test magnetic field models near dawn during the onset of an active period.

Initial CRRES Observations of Electromagnetic Ion Cyclotron Waves at L=3-7

B. J. Fraser, J. J. Singer, W. J. Hughes, J. R. Wygant, M. Smiddy, R. R. Anderson

Preliminary results of electromagnetic ion cyclotron waves (ICW) seen by the CRRES fluxgate magnetometer between August and October 1990 are presented. Over this interval the spacecraft covered the 02-10 MLT region and eighteen ICW events have been observed with frequencies from 0.2-3.8 Hz over L=3.6 - 7.3 and at geomagnetic latitudes extending from the equator up to 27° . Comparisons with the electron density profiles provided by the Iowa/AFGL Plasma Wave Experiment indicate that the waves with frequencies above about 2 Hz are seen just outside the plasmapause, while the lower frequency waves occur in the trough region. Inspection of the UC Berkeley/AFGL Langmuir Probe/Electric Field Experiment data indicates that the ICW's are also present in the electric field. The propagation characteristics of these waves in the magnetosphere will be discussed with reference to power spectra, polarization parameters and Poynting flux calculations.

Structure of Banded Electrostatic Emissions Observed by the CRRES
Satellite

C. P. Paranicas, W. J. Hughes, H. J. Singer, R. R. Anderson

Hubbard and Birmingham [1] described a scheme for classifying banded electrostatic emissions above the local gyrofrequency and have studied the implications of interpreting different types of emissions as having originated from the same basic mechanism. The CRRES satellite is ideal for studying these emissions because the spacecraft spends much of its time near the equator and at L values where they are most frequently observed. We will present the results of a survey of the so-called $n+1/2$ -type emissions. In particular, we will discuss positions of the harmonics with respect to the integral multiples of the electron gyrofrequency and the band structure of these emissions. Our initial analysis indicates that emissions in the same plasma region can have very different band structure. This may reflect local fluctuations in plasma or have consequences on the theory of the generation of these waves

[1] Hubbard, R. F. and T. J. Birmingham, "Electrostatic Emissions between Electron Gyroharmonics in the Outer Magnetosphere," J. Geophys. Res., 83, 4837, 1978.

APPENDIX 2. THE CRRES PLASMA WAVE EXPERIMENT

The following paper is to be published in the Journal of Spacecraft and Rockets.

The CRRES Plasma Wave Experiment

Roger R. Anderson, Donald A. Gurnett, and Daniel L. Odem

Abstract. The CRRES Plasma Wave Experiment is designed to provide information on the plasma wave environment and the total plasma density in the Earth's radiation belts and throughout the CRRES orbit. This information is valuable both for studying the naturally occurring wave-particle interactions affecting the plasma and particle environment in the plasmasphere and magnetosphere as well as for studying the chemical releases. The electric field sensors for this instrument consist of two long electric dipole antennas (~100 m tip-to-tip) and the magnetic field sensor is a search coil magnetometer mounted at the end of a 6-meter boom. The instrument has two receivers: a 14-channel spectrum analyzer covering the frequency range from 5.6 Hz to 10 kHz and a 128-step sweep frequency receiver covering the frequency range from 100 Hz to 400 kHz. Measurements from these receivers provide the intensity of the electromagnetic and electrostatic fields as functions of frequency and time from which the emissions and wave modes can be identified and analyzed and from which the total plasma number density can be determined.

Introduction

The major objectives of the Combined Release and Radiation Effects Satellite (CRRES) mission include studies of the natural radiation belt environment and studies of the effects of the radiation environment upon microelectronic components, performance of active chemical release experiments in the ionosphere and magnetosphere, and low altitude studies of ionospheric irregularities. In-situ measurements of the fields and waves in the vicinity of the CRRES spacecraft are essential in order to meet these objectives. Plasma waves can play a major role in changing the thermal plasma and the energetic particle populations through pitch angle scattering, particle heating, and other wave-particle interaction processes which exchange energy and/or momentum between the waves and the particles¹. Direct measurements of the plasma wave modes and intensities are essential for calculating pitch-angle diffusion coefficients and for assessing the effects of the plasma waves on the energetic particles and the background thermal plasma². The plasma wave measurements along with the field, plasma, and particle measurements from the other CRRES experiments will provide valuable data for long term studies of the radiation belt environment as well as for event studies such as those associated with geomagnetic storms and substorms and with the chemical releases.

An important output from the plasma wave measurements will be the electron number density derived from observed Upper Hybrid Resonance Frequency (FUHR) emissions and cutoffs at the electron plasma frequency^{3,4}. These measurements are obtained independent of spacecraft charging and without perturbing the plasma.

Instrumentation

The CRRES Plasma Wave Experiment instrumentation has been designed to measure the plasma wave environment in the earth's radiation belts with emphasis on high frequency and time resolution, a large dynamic range, and sufficient frequency response to cover all the characteristic frequencies of the plasma that are of interest. The CRRES Plasma Wave Experiment provides measurements of electric fields from 5.6 Hz to 400 kHz and magnetic fields from 5.6 Hz to 10 kHz with a dynamic range of at least 100 dB (a factor of 10^5 in amplitude). Magnetic field measurements from 10 kHz to 400 kHz are also possible but the dynamic range will be reduced due to the roll off of the search coil magnetometer above 10 kHz. Electrostatic dN/N measurements from 5.6 Hz up to 400 kHz are also possible via signals from the Electric Field/Langmuir Probe (EF/LP) Experiment⁵.

The Plasma Wave Experiment measures the electromagnetic and/or electrostatic fields detected by three sensors: (1) a 100-meter tip-to-tip extendable fine wire long electric dipole antenna (designated WADA for Wire Antenna Deployment Assembly), (2) a search coil magnetometer mounted at the end of a 6-meter boom, and (3) a 94-meter sphere-to-sphere double probe electric antenna (designated SWDA for Spherical-double-probe Wire Deployment Assembly) which is a part of the EF/LP Experiment. The first two sensors are the primary sensors for the Plasma Wave Experiment while the third sensor is the primary sensor for the EF/LP Experiment. A drawing of the CRRES spacecraft showing the locations of the sensors is shown in Fig. 1. The diameter of the spacecraft is approximately 3 meters.

The basic CRRES Plasma Wave Experiment instrumentation includes two receivers: (1) a Multichannel Spectrum Analyzer to provide high-time-resolution spectra from 5.6 Hz to 10 kHz, and (2) a Sweep Frequency Receiver for high-frequency-resolution spectrum measurements from 100 Hz to 400 kHz. The dynamic range for each of the receivers is about 100 dB beginning at the respective receiver's noise level. Signals from the Plasma Wave Experiment sensors and the EF/LP Experiment sensors, after buffering by appropriate preamplifiers and differential amplifiers, are routed via two sets of antenna selection switches to the Sweep Frequency Receiver and the Multichannel Spectrum Analyzer in the Plasma Wave Experiment. Signals from the Plasma Wave Experiment sensors are also provided to the EF/LP Experiment where they can be used for measuring the DC and low frequency electric fields and for waveform measurements using the burst memory. Signals from the CRRES Plasma Wave Experiment sensors routed to the EF/LP Experiment can subsequently be routed to the wave-particle correlator in the Low Energy Plasma Analyzer Experiment⁶. A block diagram of the CRRES Plasma Wave Experiment is shown in Fig. 2.

The CRRES Plasma Wave Experiment Main Electronics Package includes the Multichannel Spectrum Analyzer, the Sweep Frequency Receiver, a power supply, and antenna selection switches. Two Electric Field Preamps and the Search

Coil Magnetometer are also a part of the CRRES Plasma Wave Experiment. The mass of the Main Electronics Package is 5.06 kg. The entire Plasma Wave Experiment complement draws 0.175 Amps at 28 Volts at room temperature for a total power consumption of 4.9 Watts. This includes slightly less than 50 mW each ($3 \times 50 \text{ mW} = 150 \text{ mW}$ total) for the two Electric Field Preamplifiers and the Search Coil Magnetometer.

Sensors

Two diametrically mounted WADA units simultaneously deployed a dipole wire antenna with a tip-to-tip length of 100 meters in the spin plane of the satellite. Each WADA unit contains approximately 50 meters of a 0.813 mm (0.032 in.) diameter teflon coated 7-strand beryllium-copper wire and a 33 gram (0.073 lb.) insulated stainless-steel tip mass. The insulation is stripped from the outer ten meters of the wire. The weight of the coated wire is 1.98 grams/meter and the weight of the uncoated wire is 1.16 grams/meter. The mass of each WADA unit including wire and tip mass is 2.68 kg. Two high-input-impedance electric field preamplifiers are located on the spacecraft near the base of each half of the extendable fine wire long electric dipole. The mass of each of the two electric field preamplifiers is 0.303 kg.

The search coil magnetometer contains a high permeability μ -metal core 0.41 meter long, wound with 10,000 turns of #42 wire, and a preamplifier. The mass of the search coil magnetometer is 0.290 kg and it consumes approximately 50 mW of power. The sensitivity of the search coil magnetometer is 35 $\mu\text{V/nT-Hz}$ up to 10 kHz and then falls off at a 12 dB per octave rate thereafter.

The SWDA spherical double probe sensors are described in detail in the EF/LP Experiment article in this journal. Signals from these sensors can be used by the Plasma Wave Experiment for electric field measurements when they are in the potential mode and for electrostatic dN/N measurements when they are in the current mode.

Multichannel Spectrum Analyzer

The CRRES Multichannel Spectrum Analyzer consists of 14 narrow-band filters logarithmically spaced in frequency (4 filters per decade in frequency) from 5.6 Hz to 10 kHz followed by 14 logarithmic compressors. The design for the Multichannel Spectrum Analyzer is identical to the magnetic spectrum analyzer flown on ISEE 1⁷. The nominal 3 dB sine wave bandwidth points of each narrow-band filter are at $\pm 15\%$ of the center frequency except for the two highest frequency channels (5.62 kHz and 10.0 kHz) whose bandwidths are $\pm 7.5\%$ of the center frequency. The Multichannel Spectrum Analyzer characteristics are listed in Table 1. The logarithmic compressors produce an analog output voltage approximately proportional to the logarithm of the input signal. The 14 0.0 to 5.10 Volt DC analog outputs are sampled simultaneously 8 times per second by the Spacecraft Data Handling System.

Sweep Frequency Receiver

The Sweep Frequency Receiver covers the frequency range from 100 Hz to 400 kHz in four bands with 32 steps per band. The fractional step separation

of the Sweep Frequency Receiver, df/f , is about 6.7% across the entire frequency range. Band 1 (100 Hz to 800 Hz) is sampled one step per second or 32 seconds per sweep. Band 2 (800 Hz to 6.4 kHz) is sampled two steps per second or 16 seconds per sweep. Band 3 (6.4 kHz to 50 kHz) and Band 4 (50 kHz to 400 kHz) are each sampled four steps per second or 8 seconds per sweep. The sweep frequency receiver on ISEE 1, after which the CRRES receiver has been patterned, had each of the four bands sampled one step per second or 32 seconds per sweep⁷. To accomplish the faster sampling rates on the three upper bands on CRRES, two additional frequency synthesizer circuits were added. The nominal bandwidths of the four bands are 7 Hz, 56 Hz, 448 Hz, and 3.6 kHz, respectively. The four bands each have a logarithmic compressor which measures the signal amplitude over about a 100 dB dynamic range beginning at the noise level of the receiver and produces a 0.0 to 5.10 Volt DC analog output approximately proportional to the logarithm of the input amplitude. The sampling of the four Sweep Frequency Receiver analog outputs (one for each band) are done by the Spacecraft Data Handling System. Table 2 lists the noise levels and the minimum detectable sine wave amplitudes for the four CRRES Sweep Frequency Receiver bands.

Commands and Data Handling

The Spacecraft Data Handling System provides the clock and command lines for controlling the receivers and the sampling and the analog to digital conversions of the receivers' 0.0 to 5.10 Volt DC analog outputs. The CRRES Plasma Wave Experiment has two high-level relay commands and one 16-bit serial-digital command. The high-level relay commands turn the experiment power on and off. The serial-digital command determines which sensor is connected to which receiver and whether or not the receivers are locked onto a single sensor or cycle through all of the sensors. The Sweep Frequency Receiver and the Multichannel Spectrum Analyzer can each be independently commanded to either have their inputs locked to a single sensor or to cycle through all three sensors. The Sweep Frequency Receiver when commanded to the cycle mode cycles E-B-E-LANG at a 32 second per sensor rate (E is the WADA long wire antenna, B is the Search Coil Magnetometer, and LANG is the input from the EF/LP Experiment SWDA sensor). When commanded to the cycle mode, the Multichannel Spectrum Analyzer cycles B-E-B-LANG at a 4 second per sensor rate.

The CRRES Plasma Wave Experiment has three status words: two analog words, the Low Voltage Power Supply Monitor and the Search Coil Magnetometer temperature, and the Serial-Digital Status word which identifies the antenna selection status for each receiver and the frequency step for the SFR. The total bit rate for the Plasma Wave Experiment is 970 bits per second.

Initial Results

CRRES was launched on July 25, 1990, into a geosynchronous transfer orbit with a perigee altitude of 350 km and an apogee 6.3 Re (earth radii) geocentric. The inclination was 18.2°, the orbital period was 9 hours and 52 minutes, and the initial magnetic local time at apogee was 0800 MLT. The CRRES Plasma Wave Experiment has performed perfectly ever since it was turned on three days after launch. The electric antennas were fully extended in the few weeks after launch. The WADA has a tip-to-tip length of 100 m (for an effective antenna length of 50 m) and the SWDA has a sphere-to-sphere length

of 94 m. Following the antenna extensions, the spacecraft was spun down to approximately 2 RPM. The normal mode of operation for the Plasma Wave Experiment after the antenna extensions has been to have the Sweep Frequency Receiver locked onto the WADA antenna and the Multichannel Analyzer cycling through all three antennas.

Figure 3 shows a plasma wave spectrogram for about a two hour period on the inbound portion of Orbit 143 on September 22, 1990. The spectrogram covers the frequency range from 5.6 Hz to 400 kHz. The data from 5.6 Hz to 100 Hz are the measurements from the Multichannel Spectrum Analyzer during the portions of its cycling when it is connected to the WADA antenna. The intensity of the waves are gray-scale coded with white being least intense and black being most intense. The dashed line labeled FCE has been added to show the electron cyclotron frequency calculated from the Fluxgate Magnetometer Experiment⁸. The FUHR emissions from which the electron number density can be calculated are clearly visible in the upper right portion of the spectrogram. Much variability in the FUHR line indicates much structure in the plasma density. The time resolution above 6.4 kHz is one spectrum every eight seconds which is four times faster than the ISEE rate. The plasmopause crossing occurs at about 2225 UT and intense low frequency (5.6 Hz to 100 Hz) electric field emissions are observed just at the outer edge. Plasmaspheric hiss (from about 300 Hz to 3 kHz) is evident here only inside the plasmasphere. An ELF hiss band (from about 50 Hz to 200 Hz) is much more intense in a limited region outside the plasmopause than it is inside. Intense chorus emissions are predominantly outside the plasmopause but a weaker component of them does continue inside the plasmasphere. Outside the plasmopause electron cyclotron harmonic (ECH) bands are apparent above the chorus and below the FUHR line. The radiation from the FUHR line up to about 70 kHz is trapped nonthermal continuum radiation. Weak Auroral Kilometric Radiation emissions are visible above about 100 kHz outside the plasmopause. The striations apparent in some of the emissions are a result of the beating between the spin rate and the sampling rate. Please note the absence of any significant solar array interference at low frequencies that other spacecraft have experienced. This is due to the CRRES solar array always facing the sun and not being shadowed and to the very low spin rate.

The ability of the CRRES Plasma Wave Experiment to detect a large variety of emissions over a large frequency range and a large dynamic range with high time resolution is clearly evident. In the data we have examined so far, many interesting features have been observed that, when analyzed along with the data from other CRRES instruments, should increase our understanding of the wave-particle interactions and plasma dynamics occurring in the inner magnetosphere.

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Randall, J. S. Pickett, and R. Neppel. From the Phillips Laboratory we wish to thank H. J. Singer and W. P. Sullivan, the CRRES Plasma Wave Experiment managers, and R. C. Sagalyn, E. G. Mullen, M. S. Gussenhoven, W. J. Burke, and N. C. Maynard for their invaluable support and assistance throughout the project. We also wish to thank M. Smiddy, D. Moon, Lt. R. Redus, Lt. M. Violet, Lt. K. Kerns, and Lt. K. Ray from the Phillips Laboratory, P. Anderson from Boston University, J. R. Wygant and P. R. Harvey from the University of California, Berkeley, and R. Brown, B. Pieper, J. Cowder, and C. Holmes from Ball Space Systems Division for their assistance during the integration, calibration, and testing phases. We are also grateful to D. Evans of NASA Headquarters, D. Reasoner of Marshall Space Flight Center, and D. J. Simons and T. A. Fritz from the Los Alamos National Laboratory for their support of our participation in the CRRES chemical release operations.

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Table 1. Multichannel Spectrum Analyzer Characteristics

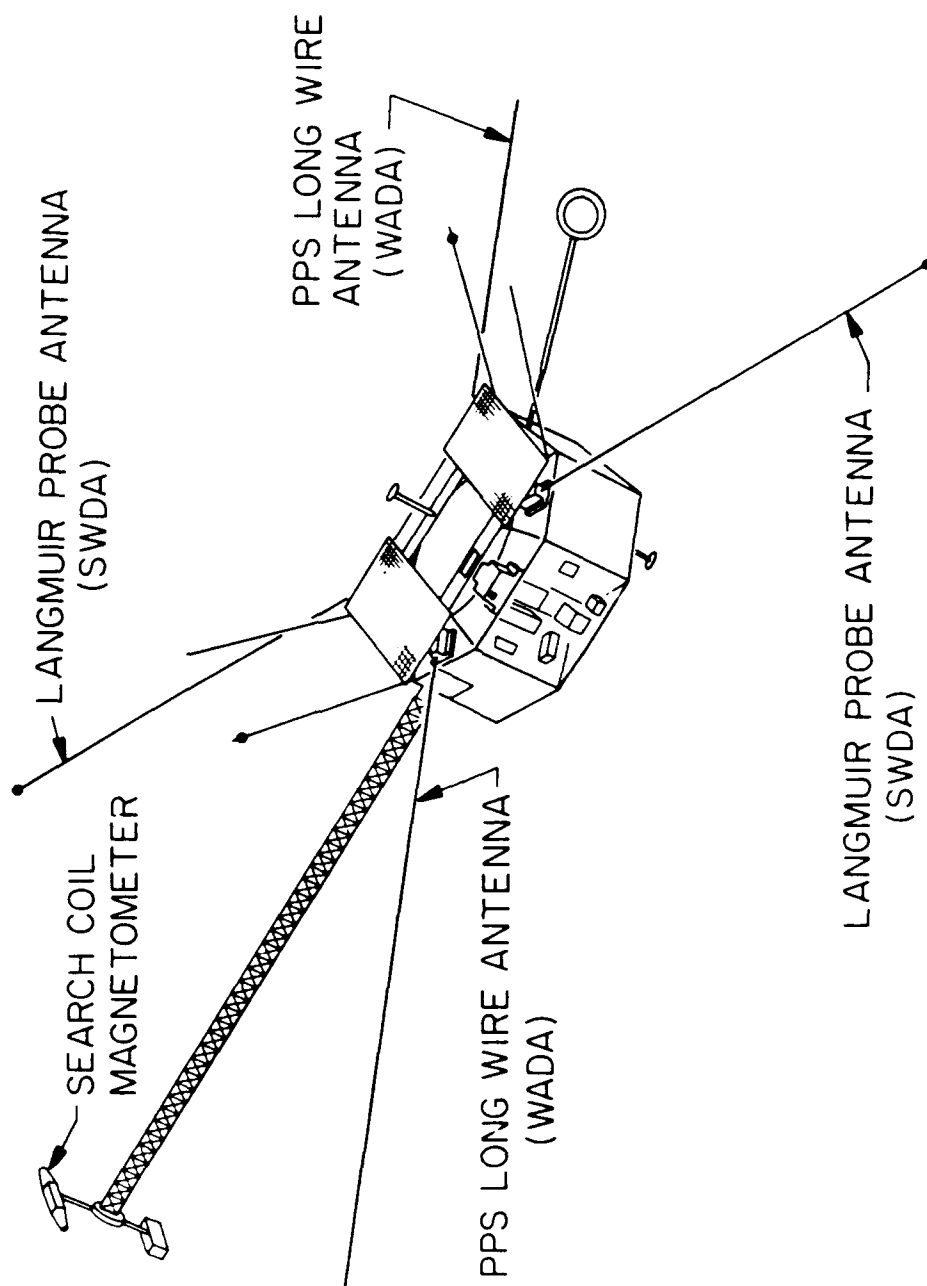
Channel Number	Center Frequency	Effective Noise Bandwidth	Noise Level (V^2/Hz)	Minimum Detectable Sine Wave Amplitude (Volts)
01	5.6 Hz	1.12 Hz	1.8×10^{-10}	1.4×10^{-5}
02	10.0 Hz	2.00 Hz	2.2×10^{-11}	6.7×10^{-6}
03	17.8 Hz	3.56 Hz	1.1×10^{-11}	6.2×10^{-6}
04	31.1 Hz	6.22 Hz	3.5×10^{-12}	4.7×10^{-6}
05	56.2 Hz	11.2 Hz	4.1×10^{-12}	6.8×10^{-6}
06	100. Hz	20.0 Hz	2.3×10^{-12}	6.8×10^{-6}
07	178. Hz	35.6 Hz	1.8×10^{-12}	7.9×10^{-6}
08	311. Hz	62.2 Hz	5.0×10^{-13}	5.6×10^{-6}
09	562. Hz	112. Hz	1.8×10^{-13}	4.4×10^{-6}
10	1.00 kHz	200. Hz	8.5×10^{-14}	4.1×10^{-6}
11	1.78 kHz	356. Hz	2.6×10^{-14}	3.1×10^{-6}
12	3.11 kHz	622. Hz	1.6×10^{-14}	3.2×10^{-6}
13	5.62 kHz	560. Hz	2.3×10^{-14}	3.6×10^{-6}
14	10.0 kHz	1.00 kHz	3.5×10^{-15}	1.9×10^{-6}

Table 2. Sweep Frequency Receiver Noise Levels and Minimum Detectable Sine Wave Amplitudes.

	Noise Level (Volt^2/Hz)	Minimum Detectable Sine Wave Amplitude (Volts)
Band 1 (100 Hz to 800 Hz) (Bandwidth = 7 Hz)	2.5×10^{-12}	4.2×10^{-6}
Band 2 (800 Hz to 6.4 kHz) (Bandwidth = 56 Hz)	4.5×10^{-13}	5.0×10^{-6}
Band 3 (6.4 kHz to 50 kHz) (Bandwidth = 448 Hz)	3.9×10^{-14}	4.2×10^{-6}
Band 4 (50 kHz to 400 kHz) (Bandwidth = 3.6 kHz)	1.3×10^{-14}	6.9×10^{-6}

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— CRRES PLASMA WAVE EXPERIMENT SENSORS —

Fig. 1 A drawing of the CRRES spacecraft showing the locations of the sensors for the Plasma Wave Experiment.

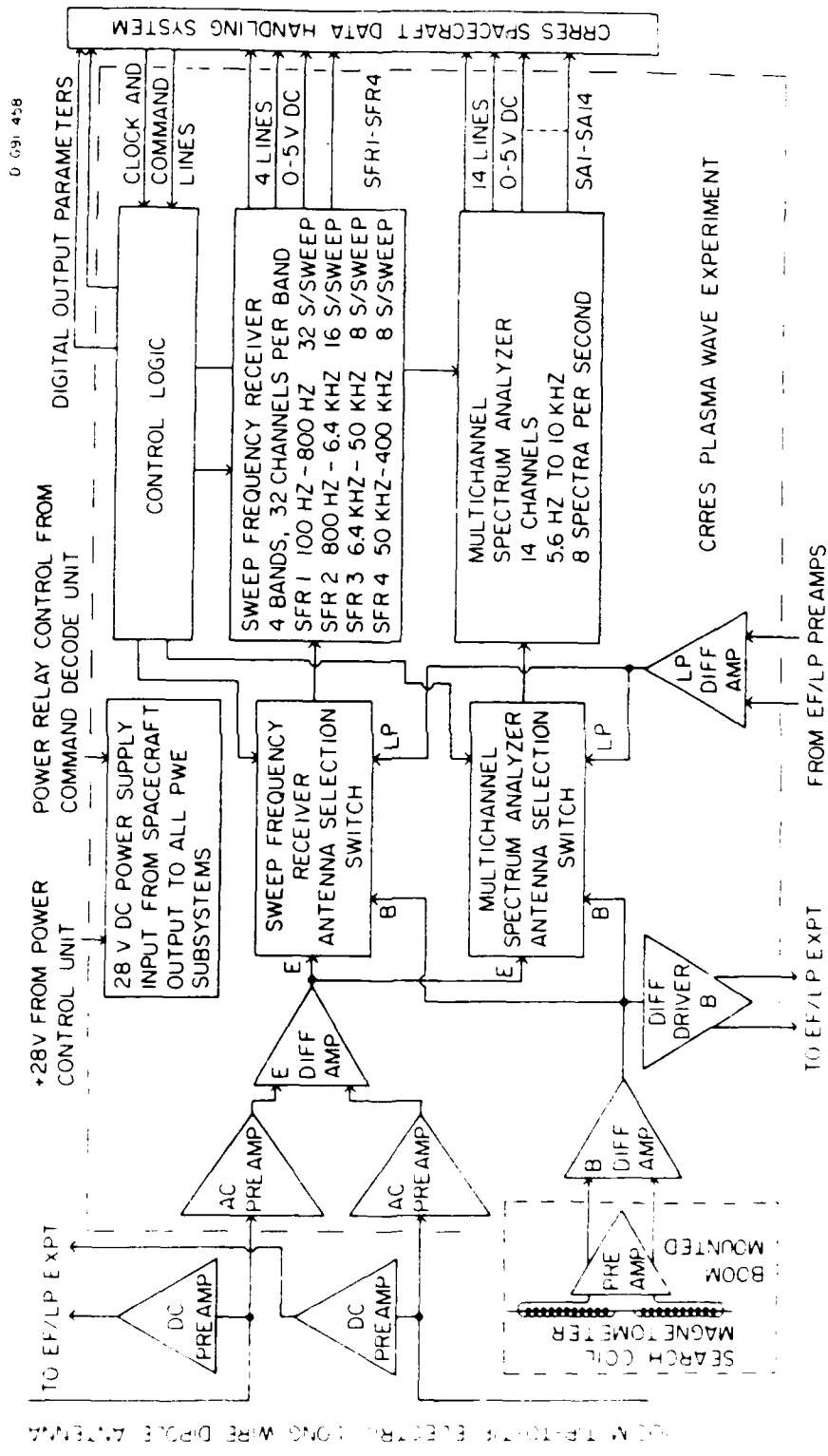


Fig. 2 A block diagram of the CRRES Plasma Wave Experiment.

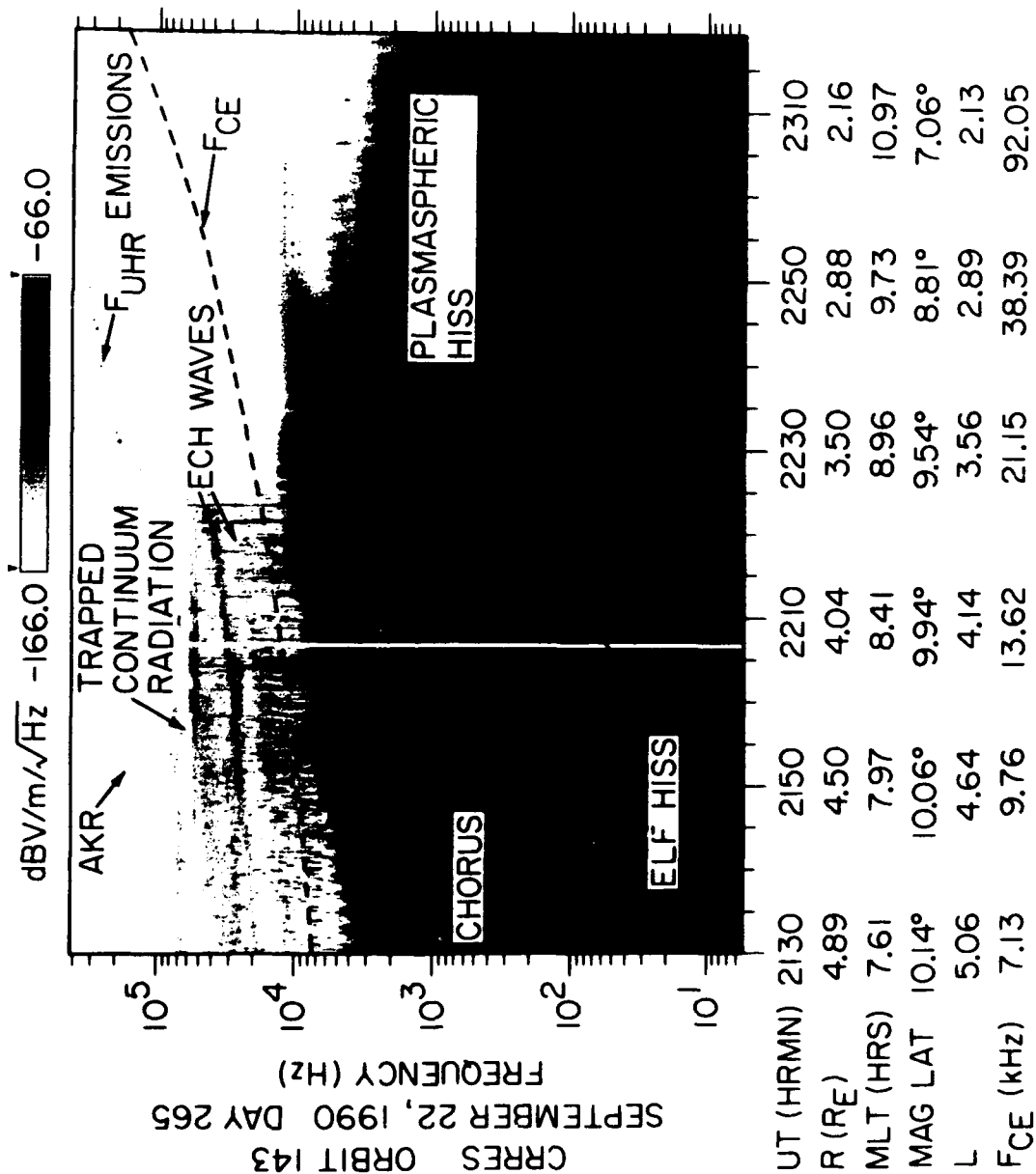


Fig. 3 CRRES Plasma Wave Experiment data obtained near the inbound plasmopause crossing on Orbit 143.